EFFECTS OF ALDER MINE ON THE WATER, SEDIMENTS, AND BENTHIC MACROINVERTEBRATES OF ALDER CREEK

Annual Report

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Effects of Alder Mine on the Water, Sediments, and Benthic Macroinvertebrates of Alder Creek

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Abstract

The Alder Mine, an abandoned gold, silver, copper, and zinc mine in Okanogan County, produces heavy metal-laden effluent that affects the quality of water in a tributary of the Methow River. The annual mass loading of heavy metals from two adits at the Alder Mine was estimated to exceed 11,000 kg per year. In this study, water samples from stations along Alder Creek were assayed for heavy metals by ICP-AES and were found to exceed Washington State's acute freshwater criteria for cadmium (Cd), copper (Cu), selenium (Se), and zinc (Zn). Specific trends were observed for each metal and concentrations varied according to three patterns: they either declined, were constant, or increased between high- and low-flow sampling periods (June through September, 1998). Surber samples were collected to compare the community structure of benthic macroinvertebrates below the mine with samples from reference sites not impacted by the mine. The density and diversity of benthic macroinvertebrates were less below the mine than above. Using the principles of epidemiology, a strong relationship was established between the discharge of metal-laden mine waste from the abandoned Alder Mine, elevated levels of Cd, Se, and Zn in Alder Creek, and the condition of the benthic community of Alder Creek. Elevated concentrations of Cd, Cu, Se, and Zn in the streamwater and sediments indicate these metals have reduced species richness and abundance in the aquatic community of Alder Creek. The extent of the problem, reaching the confluence of Alder Creek and the Methow River, indicates that there exists a significant hazard to the environment. Metals exceeding water quality criteria at the confluence of Alder Creek and the Methow River pose a risk to threatened species of

juvenile salmonids, including bull trout (*Salvelinus confluentes*), native steelhead (*Salmo gairdneri),* and chinook salmlon (*Oncorhynchyus tsawytscha*), which use the lower portion of Alder Creek as rearing habitat. A proposal has been submitted to the Bonneville Power Administration to continue the research, define the mechanisms of impact, and provide a basis for planning remediation. The initial review of the proposal by the Columbia Basin Fish and Wildlife Authority recommended against continuing the project, which awaits a final decision by the Power Planning Council. A preliminary study on annual trends in heavy metals in Alder Creek, funded by the University of Washington, Center for Streamside Studies, was scheduled for the period from September 1998 through September 1999.

INTRODUCTION

Abandoned and inactive mines located in sensitive mountain watersheds cause environmental problems in Washington State (Huchton, 1998). The ores associated with many of these mines contain abundant sulfide (sulfur-bearing) minerals. After mining exposes these minerals to water, dissolved oxygen, and ferric (Fe^{3+}) iron, chemical reactions take place that produce high concentrations of dissolved metals, ferrous (Fe^{2+}) iron, sulfate (SO_4^{2-}), and acid (H^+). Water contaminated by chemicals from abandoned mine lands often, therefore, have a low pH and contain high levels of heavy metals. Heavy metal chemicals are characterized by their strong attraction to biological tissues and their slow elimination from biological systems.

Heavy metals are elements that have atomic weights between 63.546 and 200.590 (Kennish, 1992) and a specific gravity greater than 4.0 (Connell et al., 1984). Heavy metals occur naturally in the environment in trace amounts and often fulfill an important role as micronutrients that are essential for the nutrition of living organisms. Living organisms require trace amounts of some heavy metals such as cobalt, copper, iron, manganese, molybdenum, vanadium, strontium, and zinc (Kennish, 1992). Non-essential heavy metals that are of concern include cadmium, chromium, mercury, lead, arsenic, and antimony.

Excessive levels of essential metals, however, can be toxic to an organism at concentrations not greatly exceeding those that are required for normal physiological functions. Metal toxicity causes multiple direct and indirect effects in plants and animals that concern practically all functions (Barcelo and Poschenrieder, 1990). For example, metals that exceed tolerance limits in aquatic organisms include changes in tissue morphology, physiology, growth, development, mobility, enzyme activity, blood chemistry, behavior, and reproduction. Metal toxicity in humans affect practically all functions and cause depressed bone development in children, liver damage, cardiac abnormalities, kidney damage, respiratory problems, neural damage, hypertension, and dermatological conditions.

Because heavy metals have the potential to adversely affect water quality, criteria for streamwater and sediments have been established for the protection of aquatic life. Fish appear to be more sensitive to metals than insects (Warnick, 1969) and humans can tolerate much higher levels of metals in waters than aquatic organisms. In comparison to freshwater fish and invertebrates, aquatic plants are equally or less sensitive to cadmium, copper, lead, mercury, nickel, and zinc. Therefore concentrations that protect fish and insects would also protect aquatic plants and humans. In general, the presence of naturally reproducing, self-sustaining and productive communities of invertebrates or fish should be indicative of a high quality environment.

There are, however, no single minimum or maximum limits for trace elements, no minimum need of an essential element and no safe limit for a toxic element. There are a series of minimum needs and maximum tolerances depending on the chemical form of the element, duration and continuity of exposure, and the amounts and proportions of other interacting elements that are present.

Metals have also been found to be toxic to fish (Warnick, 1969) and invertebrates (Chapman, 1963; Kiffney and Clements, 1996) across a wide range of concentrations. Metal toxicity varies in response to chemical, physical, and environmental variables and no two organisms react similarly to pollution because of the complex interrelationships between genetic factors and environmental conditions. As a result, various types of organisms have been found to be tolerant to metals and a population of tolerant organisms combined with an absence of intolerant organisms is an indication of pollution.

Biological assessment methods, which describe the structure and function of aquatic communities, populations or the condition of individual organisms, have been used routinely to measure ecosystem health and examine the impacts of heavy metals. Benthic macroinvertebrates are good indicators of water quality because of their naturally wide distribution, high abundance and taxonomic diversity. Also, because of their wide variation in sensitivity to contaminants, relative immobility, and because they are long-lived, they integrate spatial and temporal variations in exposure to contaminants. The structure and function of benthic communities can, therefore, be used to indicate whether the criteria necessary for a healthy biological community have been met.

Biological assessments alone, however, are not adequate to characterize an environmental problem. Chemical assessment methods must also be used to measure the concentration of contaminants, which are evaluated in relation to fixed criteria in order to detect possible causes of the observed biological condition. Since the range of contaminants that could be measured is enormous, a literature review on the potential contaminants in the effluents from abandoned hard-rock mines and their effects on the community structure of benthic macroinvertebrates must be used to limit the range of contaminants to be studied.

Chemical assessments that measure the concentration of contaminating metals will only suggest potential causes of environmental problems. They do not, however, take into account the interactions between metals or with other environmental factors or the effects of metals from unexpected sources. For example, heavy metals in surface water systems can be from natural as well as anthropogenic origins. For reasons unrelated to human activity, many surface- and groundwaters contain natural (background) concentrations of one or more metals that exceed water quality standards. It is clearly unrealistic, therefore, to evaluate affected waters against standards that are below natural background levels. As a consequence, the concentration of heavy metals in impacted streams must also be compared to portions of the same stream that are not impacted by contaminants or from geologically similar streams nearby.

In Okanogan County, Washington, approximately 150 mine sites have been screened by the Okanogan Public Health Department and the Washington State Department of Ecology using historical records to determine how many abandoned mine sites pose a threat to human health or the environment (Huchton, 1996). Of those sites, 36 were regarded as sufficiently hazardous to warrant sampling and analysis. Twenty-five were subsequently found to contain heavy metals that exceeded standards. At one of those sites, the Alder Mine near Twisp, Washington, cadmium was estimated to be present at approximately 2.5 times the Washington State water quality criteria (Huchton, 1998; WAC, 1992).

In this study, chemical and biological assessment methods were combined using the principles of epidemiology to establish a cause and effect relationship between the effluent from the Alder Mine and the biological condition of the aquatic ecosystem. The objectives of this study were as follows:

1) Measure the concentration of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), selenium (Se), and zinc (Zn) in streamwater and sediment samples;

2) Characterize the benthic invertebrate community structure of Alder Creek below the mine in relation to reference sites on Alder Creek and on the nearby Poorman Creek which are not affected by mine waste;

3) Describe the possible causes of the observed changes in benthic invertebrate community structure.

LITERATURE REVIEW

The occurrence of trace elements in the environment and their influence on ecosystem functions has been the subject of extensive research in diverse fields that include geology, hydrology, geochemistry, nutrition, toxicology, and biology. Since it is unrealistic to cover all aspects related to the subject of trace metals in the environment, a literature review is necessary to focus attention directly on heavy metal enrichment from abandoned mines, their fate in the context of the watershed environment, their detection, and their effects on ecosystem function.

Specifically, the focus of this literature review will be on the generation of heavy metal-laden discharge from the oxidation of sulfide minerals such as pyrite. The fate of heavy metals discharged into forest soils will also be considered as well as their fate in surface waters and stream sediments. Finally, the literature related to chemical and biological indicators of heavy metal pollution and the effects of heavy metals on ecosystem function will be considered.

Pyrite Oxidation

The ores of many mining districts contain abundant sulfide minerals. As a consequence of mining, these minerals are exposed to water, dissolved oxygen, and ferric (Fe^{3+}) iron and chemical reactions, such as the oxidation of pyrite, take place that produce high concentrations of dissolved metals, ferrous (Fe^{2+}) iron, sulfate (SO_4^{2-}), and acid (H^+). The chemical reactions that describe pyrite degradation were taken from Balistrieri (1998) where the dissociation of minerals was described by the following reactions:

$$FeS_{2\,(s)} + {}^{7}/_{2}\, O_2 + H_2O \rightarrow Fe^{2+} + 2\, SO_4^{2-} + 2H^+ \quad (1)$$

$$Fe^{2+} + {}^{1}/_{4}\, O_2 + H^+ \rightarrow Fe^{3+} + {}^{1}/_{2}\, H_2O \quad (2)$$

The abiotic rate of these reactions is slow. The bacterium *Thiobacillus ferroxidans* catalyzes the reaction in the environment so that its rate is 5 to 6 orders of magnitude greater than the abiotic rate (Singer, 1970). The bacterially mediated chemical cycle is described by the reaction where the ferric (Fe^{3+}) produced in reaction is oxidized to Fe^{2+}:

The ferric (Fe^{3+}) ion produced in reaction 2 can also further oxidize pyrite:

$$FeS_2 + 14Fe^{3+} + 8H_2O \leftrightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (3)$$

Other sulfide minerals such as sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and greenocktite (CdS) can be oxidized by dissolved oxygen. The reaction is responsible for the release of metal and sulfate. Microorganisms also catalyze these reactions but acid is not produced:

$$ZnS_{(s)} + 2O_2 \rightarrow Zn^{2+} + SO_4^{2-} \quad (4)$$

There appears to be little literature on the generation of neutral to alkaline mine drainage. Kelly et al., (1997), however, reported on the concentrations of metals in waters from undisturbed deposits in the Brooks Range where carbonate rocks buffered the system resulting in less acidic, mostly near-neutral pH surface water with low concentrations of most metals except Zn. The principal reactions that generate neutral to alkaline mine drainage, in sequential order based on reactivity, are the dissolution of carbonate minerals such as calcite ($CaCO_3$), dolominte, [$CaMg(CO_3)_2$], ankerite [$CaFe(CO_3)_2$], siderite [$FeCO_3$], oxides and hydroxides of Al and Fe, and aluminosilicates (fledspars, chlorite, muscovite) (Balistrieri, 1998).

The dissolution of calcite and other carbonate minerals results in the release of metal ions (i.e., Ca, Mg, Fe, and Mn) and bicarbonate (HCO_3^-) to solution. The dissolution of calcite exposed to water is described as follows:

$$CaCO_{3(s)} + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3 \quad (5)$$

In the presence of acid, the buffering reactions are described as follows:

$$HCO_3^- + H^+ \Longleftrightarrow H_2CO_3 \longrightarrow CO_{2\,(g)} \quad (6)$$

Fate of Metals in Forest Soil

Heavy metals from mining are a problem in forests because soil appears to be the principal reservoir for the deposition of the elements from mine drainage. Stewart and Lambeth (1993) studied a mine tailings site that was releasing heavy metals from mine waste into an unconsolidated aquifer. At a distance of 550-m downgradient from the tailings impoundment, all heavy metals were attenuated to near background concentrations. Contaminants were transported downgradient and into contact with calcite and were neutralized by calcium carbonate causing the precipitation of pH sensitive species to occur.

Experiments by Berthelsen et al. (1994), that compared the mobility of Pb, Zn, Cd, and Cu in experimentally limed and unlimed forest plots demonstrated that while liming reduced the leachability of Zn, appreciable amounts of Zn were still leached from the O-horizon. Other events must, therefore, affect the flow of contaminants and their concentration downgradient. Stewart and Lambeth suggest that other mechanisms such as advection (the mass flow of water), dilution, dispersion, and sorption must also be considered.

According to Vaughn (1977), the mobility of metals in soil depends on at least five factors: 1) soil properties such as particle size and whether they are oxides or other forms; 2) the clay and organic content of the soil; 3) the biological characteristics of the soil such as the microfloral composition and the chemical nature of the ligands, 4) extent of modification by environmental factors; and 5) soil modification by plants. The transfer of metals from soil to plants is a potentially important environmental pathway and could be an important route of entry for metals into the food chain (Vaughn, 1977).

Fate of Metals in Surface Water

A large number of freshwater streams are contaminated with metals generated by sulfide mineral oxidation. The adsorption of metals onto the hydrous metal oxide surfaces of suspended particulate matter, cobbles, and sediments in streams has been shown to be an important process (Paulson, 1997) it does appear to be generally agreed that the physicochemical forms (speciation) of the trace elements determine their availability and potential toxicity to biota.

Cowen (1986) and Schott (1984) discussed the effects of chemical speciation on metal toxicity. Cowen showed that for any pH value there will always be more than one species and that their relative concentrations change as a function of the hydrogen ion concentration. For example, as the pH increased from 7.0 to 9.0, the activities of the free ion Cu^{2+} and the CuOH species decreased in a similar manner. Because of the relationship of toxicity to the availability of aqueous forms of heavy metals, metal toxicity is also dependent on pH and the relative proportions of the more toxic ionic forms of the heavy metals.

It is generally agreed that there is a decrease in biological activity with increasing hardness due to precipitation and the formation of carbonate and hydroxide complexes. Jones (1938) presented evidence that the toxicity of Pb, Zn, and Cu to fish was reduced by the addition of Ca^{2+}. Complexation of solute trace elements by organic ligands also decreases their biological activity. According to Jenne (1997), the formation of inorganic and organic complexes may be the most important factor in reducing metal toxicity in hard waters. The most common sinks for trace elements are iron plus manganese oxides, sulfides, aluminum and silicon oxides, and basic sulfate and chloride salts of the metals in very concentrated solutions and evaporites (Jenne, 1977).

Water quality criteria (WAC, 1992) currently take into account the hardness of the water because acute toxicity experiments have shown that metals are more toxic in soft water than in hard water. Variations in metal toxicity are due to one or more interrelated ions such as hydroxide, carbonate, and bicarbonate (alkalinity), calcium or magnesium (hardness). The ions form a range of heavy metal complexes that may diminish the toxicity of metals. When calculating water quality criteria, hardness is used as a surrogate for those ions that affect metal bioavailability.

Fate of Metals in Stream Sediments

Metals such as Cd, Cu, Ni, Pb, and Zn are often elevated over background levels in sediments due to mining and other human activities. Concentrations of metals that cause toxicity can vary, however, by one or more orders of magnitude among different sediments (DiToro, 1990). The toxicity of chemicals in sediments is determined by the degree to which chemicals bind to the sediment. This modifies the chemical potential of the metals and, as a consequence, different sediments exhibit different degrees of toxicity.

While sediment concentrations of metals have been found to be orders of magnitude greater in stream sediments than in the water column (Bissonette, 1977 in Drucker), the assimilation rate of metals from solid-food sources is orders of magnitude less than the rate of assimilation of dissolved trace elements (Jenne, 1977). Although it is generally believed that benthic organisms and invertebrates, which exist in, on or around sediments, may accumulate metals from this environment, a study by Jenne (1977) showed there was only a weak correlation of metal concentration in aquatic sediments with metal concentrations in sediment ingesting aquatic fauna.

Sediment quality criteria, therefore, must be based on the fraction of metal that is bioavailable (Ankley, 1996). A key to the bioavailability of sediment contaminants has been correlated with the interstitial water concentrations. An important binding phase that controls interstitial water concentrations of the metals is an extractable fraction of iron sulfides known as acid-volatile sulfides (AVS).

AVS binds, on a mole-to-mole basis, a number of cationic metals of environmental concern (e.g., Cd, Cu, and Zn) forming insoluble sulfide complexes with minimal biological activity (Ankly, 1996). DeWitt and Swartz (1996) concluded that AVS is the dominant binding phase for Cd in anaerobic sediment confirming the general belief that AVS is composed principally of solid-phase iron monosulfides (FeS). Hansen (1996) recommends that a metal to AVS ratio be used as a more accurate prediction of metal bioavailability but warned that the potential for release of nonavailable metal as a result of oxidation of AVS (including both iron and Cd and other toxic metal sulfides) may be part of the normal seasonal sulfide cycle. It is a commonly held assumption that metals are immobilized in high-pH surface waters. Brick (1996) however, showed that photoreduction and pH-dependent adsorption-desorption are two processes that cause diel cycling of metals in freshwater. Metal concentrations in the Clark Fork River in Southwestern Montana increase 2-3-fold at night as pH and dissolved oxygen decrease. While these daily events are small relative to seasonal cycles, they expose aquatic life to high concentrations of metals that coincide with the increased nocturnal activity of benthic macroinvertebrates. Metals in sediments might, therefore, release trace elements from sediments to the overlying water column.

Chemical Indicators of Metal Pollution

Water pollution has been recognized as an environmental problem as well as a threat to human health since early in the 19th century and chemical assessment methods have been used routinely to assess the potential hazard from pollution. The results of chemical assessments are often evaluated in relation to fixed criteria. Although criteria are used to describe the possible cause of environmental problems, results that meet criteria provide no assurance that the aquatic biota are being affected by unexpected mixtures or interactions.

Water quality criteria for the protection of aquatic life are largely based on laboratory experiments to protect all life stages of the test organisms which are used a surrogates for organisms in natural systems. Water quality criteria, required under the

Federal Water Pollution Control Act Amendments of 1972, are based on a 96-hour LC50 protocol (Cowen, 1986) that identifies the concentration of a particular metal that is lethal to 50% of the organisms used as indicators of metal sensitivity.

According to Cowen (1986), the 96-LC50 values for a specific metal and taxonomic category can vary by as much as three orders of magnitude. This is further complicated by inter-element interactions that affect the minimum needs and maximum tolerances of organisms to toxic elements. Two-way interactions between Cd and Zn and three-way interactions between Cu, Mo and sulfate have been described that alter their toxicities (Underwood, 1974). While the variability of toxicity among metals and taxonomic groups under different circumstances makes the application of a single set of water quality criteria to all water bodies difficult, the development of site specific criteria is expensive and time consuming.

The analytical methods commonly used to assess metal contamination in water and sediments include tests for total metals and dissolved metals. Total metals include all metals organically and inorganically bound, both dissolved and particulate. Most samples require digestion before analysis to reduce organic matter interference and convert metal to a form that can be analyzed by Inductively Coupled Plasma mass spectroscopy (ICP-AES).

When using ICP-AES, liquid samples are introduced into a plasma discharge (ignited ionized argon gas) as an aerosol. The elements in the test sample emit light at their characteristic wavelengths. The light is transmitted to an optical system where the magnitude of the current is proportional to the light intensity. The current is integrated over a predefined period of time that is proportional to the concentration of the individual metals.

Biological Indicators of Metal Pollution

The use of a particular plant or animal to measure the condition of an environment depends on the ability of the organism to indicate the presence or absence of a particular factor, in this case heavy metals. Since toxicity is a chemical phenomenon, it begins with a reaction between a chemical and an organism at the molecular level. The initial reactions generate secondary and tertiary responses that ultimately affect populations and ecosystems (Figure 1). Since effects can be expressed at any level of organization, there are potential indicators that exist at each level (Hodson, 1990). The degree to which cause and effect are related (i.e., specificity) and our knowledge of the mechanisms of toxicity decreases at higher levels of organization.

Aquatic organisms have also been used as indicators of water pollution for over 150 years (Davis, 1995). Likewise, benthic invertebrates have been used to assess the effects of heavy metals in streams since the early 1900’s. Early research to assess the biological condition of rivers polluted by mine effluent include a study that started in Wales in 1919 concurrent with the cessation of lead mining in the Aberystwyth district of Cardiganshire. Carpenter (1924) reported that the river Ystwyth was generally barren except for algae when compared to reference streams. Newton (1943) called attention to the destructive effects of Zn pollution from abandoned metalliferous mine-workings when they returned to the river Ystwyth in 1940.

Jones (1940) found that the death of fish due to the toxic action of Pb, Zn, and Cu was related to the interaction between the metallic ion and the mucus secreted by the gills. A film of coagulated mucus was formed on the gill membranes that impaired their respiratory efficiency to such a degree that the fish were asphyxiated. It was also noted that the addition of Ca^{2+} reduced the toxicity of metals and the interaction between the heavy metal and the mucus of the fish did not occur.

In 1958, Jones documented the persistent effects of heavy metal pollution on the fauna of the River Ystwyth where the biological condition below the mine remained 35

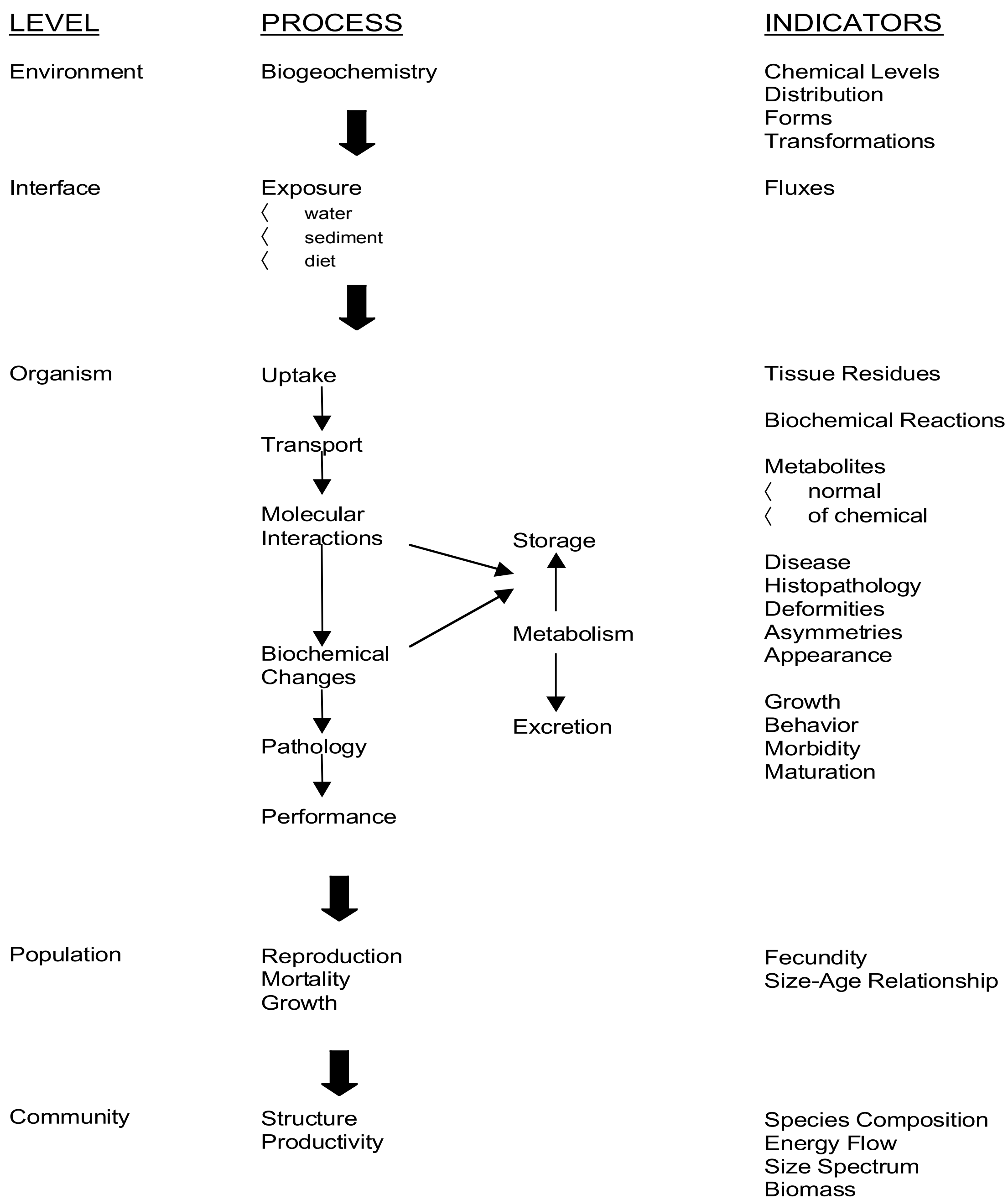

Figure 1. Conceptual diagram of the progression of chemical toxicity through different levels of organization. Indicators of exposure and effect are given for each level, however, the lists are not exhaustive (Hodson, 1990).

years after the cessation of mining. Similar studies have since been conducted in North America on rivers impacted by mines. Biological methods have been used since the effects of mines were first assessed and they continue to be used today.

Other examples include studies by Rasmussen et al. (1988) in which a negative correlation was shown to exist between numbers of taxa and concentration of dissolved iron; Wellnitz (1994) who measured the influence of iron, manganese, and blooms of iron-depositing bacteria (*Leptothrix opchracea*) on macroinvertebrates; and Parsons (1997) demonstrated the effects of iron, Cu, lead, Zn, aluminum, and magnesium in acid mine wastes on aquatic ecosystems in Iowa.

A good review of the history of the development of biological indices can be found in Davis and Simon (1995). There are at least 37 biotic indices (Hellawell, 1978; Davis and Simon, 1995; Clements, 1992; and Parrish, 1983). Approximately half (18) of the biotic indices reviewed are pollution indices that are used to communicate the impact of pollution on aquatic life and by inference, the potential risk to human health. Thirteen of the biotic indices of pollution are quantitative measures that are presumed to assess the impact of pollution in the absence of reference sites. Five are qualitative indices that compare reference sites with sites being assessed.

Biotic indices are often cumbersome and depend on the collection of extensive physical and chemical data for each geographic location where they are to be applied (Parrish, 1983). Karr's benthic index of biotic integrity (Karr, 1997) and the Hilsenhoff Biotic Index (Hilsenhoff, 1987) are two examples. The index of Community Sensitivity (ICS; Clements et al., 1992) addresses the impacts from metal pollution specifically but it requires that the dominant taxa within a region be ranked from most sensitive to least sensitive for one metal, and it then assumes that the ranking for another metal will be similar. The Montana Department of Environmental Quality has modified the Hilsenhoff Biotic Index to include tolerance values of benthic macroinvertebrates to metals

(Montana DEQ, 1998). The Montana DEQ Biotic Index is the sum of the proportional abundance of a taxon in the sample times the tolerance values specified for all taxa in the sample. Values ranged from 0 (intolerant) to 10 (tolerant).

Parrish and Wagner (1983) described an Index of Community Structure that was sensitive to water pollution and measured community composition relative to a reference. The method uses an average chi-square test and the result was a dimensionless distance that was linear and independent of sample size.

Statistics of Benthic Invertebrate Sampling

It is generally believed that purely quantitative routine sampling in streams to determine weights and numerical data is impractical. The labor and time involved in routine collection and taxonomic analysis of bottom samples demand that only a small number of samples are taken at any one time and a compromise between sample level and effort is necessary.

According to Needham (1956), the total weights of organisms showed tremendous variation and at least 194 samples are required to give significant figures. They also showed that 73 samples were required to give significant figures for total numbers at the 95% level of significance. The frequency of occurrence of the abundant or common kinds or groups of organisms was much less variable.

Gaufin (1956) presented evidence that as many as 10-15 percent of species were not encountered, on the average, until at least 8 samples had been taken. Hellawell (1978) confirmed this, and looking in more detail at qualitative surveys based on species lists, found that more than 50 percent of the species present were collected in the first sample. After that, species were added until the eighth sample. Larger samples were likely to contain only the rarer and more widely dispersed species. Needham (1956) concluded that 2 or 3 samples would be sufficient to ensure, at a 95% level of confidence, that at least one representative of each of the most common genera would be detected.

Harris (1957) was able to show that for the more common taxa, found at higher frequencies, fewer samples were required. Needham (1956) concluded that the number of samples required to be 95% sure that at least one of a group of organisms will be present varied based on taxa. For example, *Baetis,* a relatively common mayfly, required 2 or 3 samples while *Rhyacophila*, a less common caddis fly, required 9-13 samples. Thorup (1970) added that about 20 samples were needed to give reliable estimates for the suite of dominant taxa in an invertebrate community.

Elliott (1971) described a formula for calculating the number of sample units to be used in quantitative studies. Approximate means and variances must be known from pilot survey to give minimum number per sample (e.g., 47 individuals per Surber sample in the study). From this, can estimate the likely precision from a given number of sampling units (e.g., 3) can be estimated:

$$n = \frac{t\,s}{D \times \text{means}}$$

n = number of sampling units
t = students t for required probability estimate at 2 degrees of freedom

s = standard deviation (e.g. 5)

D = relative error
Mean = Mean number of individuals per Sample

If n = 3
t = 2
s = 5
D = Unknown
mean = 47

then 3 = 2 x 5/D x 47
D = 10/3 x 47
= 0.07 or 7% error with a probability of 95% ($t \cong 2$)

Integration of Biological and Chemical Assessments

Several methods have been used to analyze the effects of human activities on aquatic environments including a variety of chemical and biological methods. While biological assessment methods are used to describe the structure of aquatic communities and measure ecosystem health relative to a reference ecosystem, chemical assessment methods are used to describe the chemical exposure of aquatic biota to a suspected cause of the environmental problem.

Hodson (1990) described four categories of chemical contamination problems that affect aquatic ecosystems. A summary description of the four categories is as follows:

Category I. Known Cause, Known Effect - The relationship between the cause and the effect is clear. The presence of chemicals above specific criteria or symptoms specific to a single chemical or group of chemicals, leads immediately to a diagnosis of chemical toxicity and to a recommendation for remediation;

Category II. Known Cause, Unknown Effect - Chemicals have been detected in an ecosystem but the effects are not obvious. The challenge is to distinguish changes that exceed the normal range of variability and that suggest a chemical etiology, as distinct from other anthropogenic causes such as habitat destruction;

Category III. Unknown Cause, Known Effect - Ecological damage such as a fish kill is observed and a chemical cause is only suspected.

Category IV. Unknown Cause, Unknown Effect - Monitoring the status of an indicator species to detect the appearance of new contaminants early enough to avoid significant ecological damage.

There can be numerous possible cause and effect relationships related to either category II or III above. To establish a most likely candidate, Fox (1989) summarized the epidemiological criteria necessary for a systematic evaluation of the data: 1) Time-order.

Cause precedes effect; 2) Strength of Association. Effect relatively large or frequent; 3) Plausibility. Relationship makes sense; 4) Experimental Evidence. Observed relationships are consistent with laboratory studies; 5) Remediation. Does remediation lead to fewer symptoms; 6) Coherence of Association. Observed relationships are consistent with known mechanisms of effect; 7) Biological Gradient. There is a strong dose-response relationship; 8) Specificity of Association. Alternative hypotheses can be eliminated.

According to Fox (1989), failure to satisfy these criteria does not negate the hypothesis that there is a cause and effect relationship. Instead, it points to gaps in knowledge. For example, in regards to time-order, this is difficult in systems in which there is little historic data. Other criteria, however, such as strength of association, the effects of remediation, the existence of biological gradients, and the ability to eliminate alternative hypotheses are often determined experimentally. Criteria related to plausibility of the cause and effect relationship, consistency with laboratory results, and the coherence of association can be inferred from published accounts in the literature.

Heavy Metal Effects on Ecosystem Function

There is abundant literature showing that benthic communities impacted by heavy metals are characterized by reduced species richness, reduced abundance, and a shift in the community structure (Clements et al., 1992; Rasmussen, 1988; Percival, 1929; and Wellnitz, 1994). The River Continuum Concept in combination with the nutrient spiraling concept describe the interaction of biological and physical processes along the stream gradient and emphasize the metabolic and nutrient retention roles that streams play (Minshall, 1985). Nutrients are displaced downstream as they are cycled. The coupling of transport and cycling is termed spiraling and the ability of a stream to utilize nutrients is associated with the tightness and magnitude of the cycles.

Cairnes (1971) discussed the role of benthic invertebrates and stated that the elimination of a small portion of the complex bottom fauna will be compensated and the role filled by other organisms. The food cycle and the system as a whole will remain stable if the community is diverse and the changing environment eliminates only a small portion of the complex bottom fauna. Wallace (1982) showed experimentally that a significant reduction of lotic insect fauna will reduce the breakdown, utilization, and subsequent downstream transport of organic matter, indicating that consumers are important in regulating energy flow and nutrient cycling in stream ecosystems. The physical retention and macroinvertebrate processing are important mechanisms for closing or tightening the recycling process in streams and preventing the rapid throughput of materials. For example, Wallace (1977) suggests that filter feeders, through their capture of seston, impede the downstream transport of organic matter and serve to reduce the distance between spirals.

MATERIALS AND METHODS

Description of Study Site

Location

Alder Creek occurs in a semi-arid watershed located approximately five kilometers south of Twisp, in Okanogan County, Washington (Figure 2). The Alder Mine (Figures 3-5) is located approximately 322 meters east of Alder Creek in forest land on the western slope of McClure Mountain (Twn. 33N, Rng. 21 E, Sec. 25, 26, 35, and 36) at an elevation of 1097 meters and with a slope of approximately 26%. The mine is on privately owned property surrounded by U.S. Forest Service property (and partially on USFS property). The Alder Mine was a gold, silver, Copper, and zinc production mine from before 1937 to 1953. Effluent from the Alder Mine impacts Alder Creek approximately 1.0 km below the source of the east tributary (Figures 3 and 6).

Stream Characteristics

Alder Creek and the unimpacted Poorman Creek (Figure 3) are second-order streams that originate at approximately 1000-m and terminate at approximately 500-m. Gradients for both streams range between 5 and 15% (Average 9.5%). Alder Creek drains a watershed that is approximately 21 square kilometers (8 square miles). The stream flows underground through an area of unconsolidated sediments (alluvium and glacial deposits) starting 1 km downstream from the mine and reemerges approximately 4 km downstream.

Surface current speed was measured at the specified sample locations by timing floating objects over a fixed distance. The width of both streams averaged approximately 1.0 meter and ranges in width from approximately 0.5 meters at the headwater stations 1, 9, and 10 (Figure 3) to over 1.5 meters at downstream stations. Depth ranged from 5.5 to 25 cm and averaged 4.5 cm. On 18 June 1998, current speed was less than 0.6 m/sec. (flow<0.03-m^3/s) at the headwater stations 1, 9, and 10. The highest current speed was

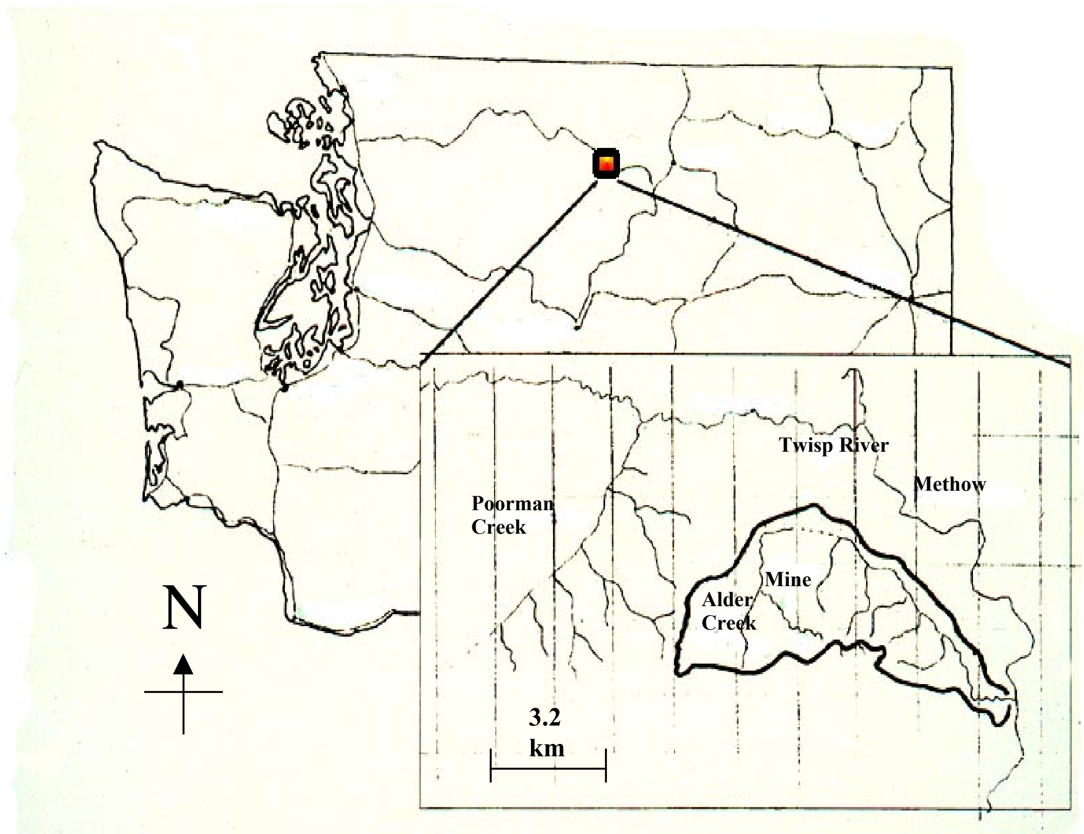

Figure 2. Washington state map with inset showing location of Alder Creek and Poorman Creek study areas.

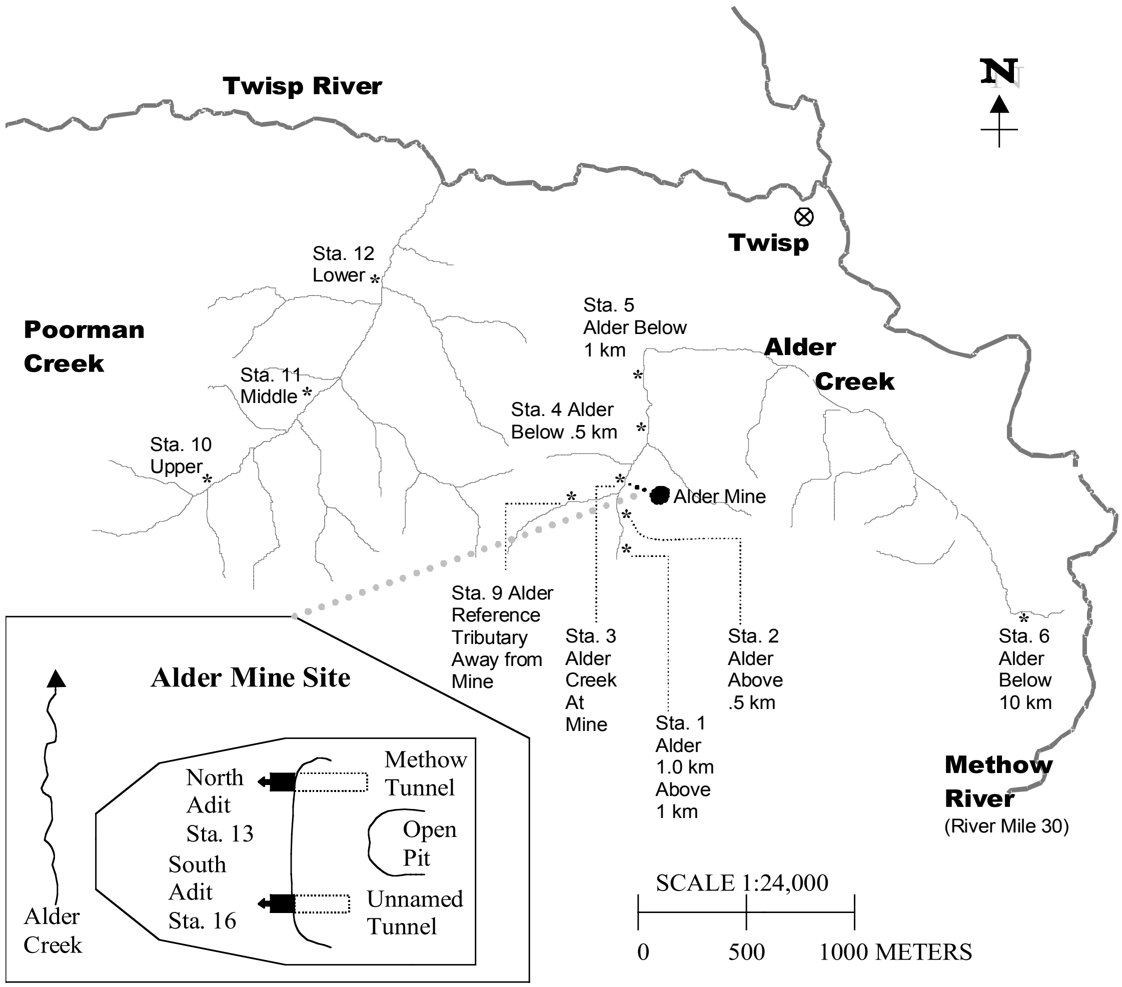

Figure 3. Washington State map with inset showing location of Alder Creek and Poorman Creek study areas.

Figure 4. Heavy metal-laden effluent from the adit Station Number 13. See Figure 2 for map showing station numbers and locations.

Figure 5. Retention pond receiving heavy metal-laden effluent from adit Station Number 13. See Figure 3 that indicates location of sample stations and identification numbers.

Figure 6. Alder Creek where heavy metal-laden effluent from mine enters creek. Location is approximately 100-m above Station Number 3. See Figure 3, which shows location of sample stations and identification numbers.

1.0-m/sec. (flow<0.3-m^3/s) recorded at the station farthest downstream (Station 6). On 2 September 1998, current speeds at stations 1, 9, and 10 were less than 0.15 m/sec (flow < 0.2 cm/s). The highest current speed recorded was 0.6-m/sec. at station 6 (flow<0.08-cms; Appendix A). Stream substrate was dominated by pebbles 2 to 64 mm in diameter. Embeddedness averaged 31%. Canopy cover was approximately 70%.

Geology and Mineralogy

Ore was mined from an open pit and at least three tunnels (Okanogan Pub. Health, 1997). Two adits (Stations 13 and 16, Figure 3) discharge metal laden groundwater. Figure 5 shows adit Station 13, the effluent stream and retention pond. Production included 6,831 tons shipped in 1939 (Hunting, 1956), 9,000 tons in 1940, and 4,000 tons in 1942 (Burnet, 1976). The ore shipped in 1939 averaged 0.55 oz/ton Au, about 0.5 oz/ton Ag, and 0.16 oz/ton Cu (Hunting, 1956). The ore came from rocks made largely of chemically precipitated silica in a 15- to 75-foot (4.6-22.9 meters) wide zone of Cretaceous-Jurassic plutonic (intrusive) igneous stock (granite) in the Newby Group of volcanic rocks. Slope position of the Alder Mine is mid to lower one-third at approximately 30% with a western aspect.

The Newby Group was intruded by the Alder Creek stock, which has been dated at 137 $\pm$ 3.4 m.y. (Burnet, 1976; Bunning, 1990). Ore minerals were deposited possibly during the emplacement of the Alder stock (Barksdale, 1975). Sulfide deposits in the Alder Mine are associated with the host rocks. Sulfide minerals include pyrite (FeS_2), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and galena (PbS). The veins of sulfide minerals are small and have no relation to the Alder stock that intrudes the volcanic rocks.

Climate

The climate of the Alder Creek and Poorman Creek study areas are within the Cascade Mountains strong rain shadow. Summers are characterized by extended periods without precipitation. Mean annual precipitation is 25 – 38 cm and the mean annual temperature is below 10^0C (USFS, 1998).

Vegetation

Relatively xeric and cold forest types predominate where Douglas-fir (*Pseudotsuga menziesii,* Mirb. Franco) and ponderosa pine (*Pinus ponderosa, Dougl. Ex Lond)* are the major climax species. Vegetation at the site is characterized by Douglas-fir and ponderosa pine which dominate the overstory. Pinegrass (*Calamagrostis rubescens*) dominates the understory to the extent that other species are inconspicuous. Shrubs are normally a minor component of the stand.

Soils

Soil texture is sandy loam to sand and the parent material is granitic rock. Soils are generally classified as Haplorthods (Gray Wooded soils; Franklin, 1973). Surface soils are slightly acid and become more neutral with depth. Soils in moister, cooler sights show some evidence of podzolization, have moderately thick accumulations of duff and litter.

Fauna

Alder Creek and Poorman Creek are utilized by resident brook trout (*Salvelinus fontanilas)* for habitat and spawning. A series of beaver ponds and cattail marshes occur 4 6 km below the mine and provide nesting sites for waterfowl, game and songbirds. Endangered and threatened species of juvenile salmonids, including bull trout (*Salvelinus confluentes)*, steelhead (*Salmo gairdneri)*, and chinook salmon (*Oncorhynchyus tsawytscha*) use the lower portion of Alder Creek as rearing habitat. Inhabitants of the Alder Creek near its confluence with the Methow River watershed also include two amphibians, the Pacific Treefrog (*Hyla regilla*) and the Spotted Frog (*Rana pretiosa*). Blackbear (*Ursus americanus*), muledeer *(Odocoileus hemionus*), snowshoe rabbits (*Lepus americanus)* and the bobcat (*Felis rufus)* also inhabit the area. Unidentified species of bats have also been observed leaving the mine entrances.

Field Procedures

Location of Sample Stations

Six sample stations along the mainstem of Alder Creek basin were selected for study based on habitat comparability, substrate class, access, depth, and flow (Figure 3).

One additional site on a tributary of Alder Creek that were distal to the mine and in the adjacent Poorman Creek drainage were included as references in the Alder Creek study. Four stations (7, 8, 14, and 15) were identified but not used as part of this study. Sample points were located with a Trimble (Sunnyvale, CA) GeoExplorer (handheld) GPS unit. Individual files were collected for each sampling point.

GPS locations were differentially corrected using Trimble Pathfinder Office (version 1.1) software. GIS data were obtained from various sources, including the OKNF (for vector data, including streams and roads) and from the USGS (for raster DEM data). GIS data analysis was performed with ARC/INFO and ArcView software (ESRI, Redlands, CA), and displays were created with ArcView.

Substrate Characterization and Embeddedness

Both instream habitat characteristics and pollution affect invertebrate communities. Habitat conditions were measured to help differentiate their effects on the benthic community from effects due to discharges from the Alder mine site. Watershed features, riparian vegetation, instream features, aquatic vegetation, and sediment/substrate characteristics were determined in conjunction with the habitat assessment.

Substrate type was determined at each sampling location by visual determination of percentage of each particle type. Mean particle size was calculated by multiplying the median particle size (phi) by the percentage present and summing all values (Cummins, 1962). Embeddedness was estimated at each sampling location by observation of the relative proportion of larger particles surrounded by fine sediment. This was done by removing a few rocks from the bottom, finding the sediment line on each rock (usually evidenced by a color change), and estimating the proportion of the rock below this line. Surface current speed was measured at the specific sampling locations by timing floating objects over a fixed distance. An average percentage of canopy cover was estimated for the reach extending from 50 meters upstream to 50 meters downstream of the sampling locations.

Salmonid Survey

The survey for juvenile salmonids was conducted by direct underwater observation (snorkeling). The study area included three pools. The pools contain cover from undercut banks, overhanging riparian vegetation, stumps, roots, coarse woody debris, and submerged aquatic vegetation.

Chemical Sampling

Surface water and sediment samples for chemical analysis were collected in triplicate near high- and low-flow conditions between (June and September 1998) at each of the 11 sample stations. Surface water samples were also collected at the Alder Creek sample station nearest the mine outfall and the Poorman Creek reference station (Stations 3 and 11 respectively; Figure 3). A subsample of the water was filtered (Gellman 0.45 micron, HT Tuffryn Membrane, disposable 25 mm sterile disposable Acrodisc filter) to measure the dissolved metal concentration. All water samples were preserved with 0.15% nitric acid and stored at ambient temperature. The analyses for metals were performed within 30 days of sample collection.

Temperature, pH, Stream Flow, DO, Alkalinity, and Hardness

Temperature, pH, flow, dissolved oxygen, and alkalinity were measured in situ at each sample site. Determination of dissolved-oxygen was made in the field using the Winkler Titration method (LaMotte Test Kit Model 221788). Alkalinity was measured in the field using the LaMotte Direct Read Titration Kit (Model 221780). Water temperature at each station was measured using a digital thermometer and hydrogen-ion concentration (pH) was determined using a Piccolo Model HI 1295 temperature compensated digital pH meter. Continuous monitoring of stream temperature occurred at stations 3 using a Hobo Model H8 One-Channel Temperature Logger.

Benthic Sampling

A 0.09 m^2 fine-meshed Surber sampler (15 meshes/cm, 0.66 mm/mesh) was used to collect six samples at each station between June 1998 and September 1998. The samples were collected from riffles in the same general vicinity as the water and sediment samples. At each of the sample sites, Surber samples were taken and sorted following standard procedures for the analysis of benthic macroinvertebrates (Green, 1997). Samples were sorted and specimens were identified and used to analyze community structure.

Laboratory Procedures

Chemical Analysis

Preserved samples of water and sediment were transported to Seattle for analysis at the University of Washington, College of Forest Resources laboratory. All samples were analyzed for total and dissolved metals. Standard methods that comply with Washington Department of Ecology and U.S. Environmental Protection Agency guidelines were used. All chemical analyses for heavy metals were performed using assays for total metals by ICP atomic emission spectrophotometry (ICP-AES; Thermo Jarrell Ash ICAP 61E).

Biological Analysis

Taxonomic identifications were made primarily from Merritt and Cummins (1984) but Lehmkuhl (1979) was also used. Organisms were identified to the lowest practical level using a 7-45X stereoscope. Each taxon found in a sample was recorded and enumerated in a laboratory bench notebook. Any difficulties encountered during identification were noted in the laboratory notebook.

Data Analysis

The following metrics and indices were analyzed from Surber samples: 1) Total Taxa Richness; 2) Number of Ephemeroptera Taxa; 3) Number of Plecoptera Taxa; 4) Number of Tricoptera taxa; 5) Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness; 6) Taxa Percent Contribution of the Dominant Taxon; 7) Abundance; 8) the 5-metric Benthic Index of Biotic integrity which combines taxa richness, EPT and percent dominance (Karr, 1997); 9) *Baetis* (number of individuals); 10) Shannon-Wiener Diversity Index; and 11) Index of Community Structure (Parrish, 1983).

Chemical and biological results were analyzed using analysis of variance procedures to look for significant differences in metric scores among stations. Regression analyses were conducted to determine whether or not there was a correlation between biological and physicochemical parameters.

QA/QC

Field Blanks

Deionized water was exposed to the sampling equipment and added to sample containers containing preservative. Field blanks were prepared in the field under the same conditions as field samples. Field blanks were prepared and submitted with high-flow, trend, and low-flow samples.

Spikes

Samples of water with known amounts of metals were submitted with test samples. Spikes were prepared in the field under the same conditions as field samples. Spikes were prepared and submitted with high-flow, trend, and low-flow samples.

RESULTS AND DISCUSSION

Metal Constituents of Mine Drainage

Water contaminated by chemicals from abandoned mine lands often have a low pH and contain high levels of heavy metals. At the Alder Mine, however, the two adits that are the sources of effluent are different in pH. Effluent collected at the portal to the mouth of the mine tunnel at Station 13 was very acidic ($pH < 3$) while the southern adit (Station 16) was near neutral ($pH = 7.1 \pm 1$; Table 1). Adit Station Number 13 was also significantly higher in sulfates and iron. The metal content in the drainage from the two adits was also distinct. Although native Cu was mined from adit Station Number 16 (LaMotte, 1998), the acidic drainage from adit Station Number 13 contained higher levels of dissolved Zn, Ni, Cu, Pb, Cr, and Cd.

The literature describing the effects of acidic mine drainage is extensive. For example, Alpers (1992) discussed water-quality and discharge data for acidic mine waters at Iron Mountain, California where acidic drainage produced at the mouth of a tunnel hadstudied had pH values that ranged from 0.6 to 2.8 but were most commonly between 1.5 and 2.5.

The concentrations of Cu, Zn, and Cd, as measured by Alpers at Iron Mountain, were approximately 30 percent of those measured in another nearby mine. The poor correlation observed between the portals studied by Alpers was interpreted as an indication that the drainage from the two portals do not have a common hydrologic connection that originates from the same mineral deposit (Alpers, 1992).

At Alder Creek, the dominance of Zn by more than one order of magnitude over Cu in the mine drainage indicates that significant oxidation of sphalerite (ZnS) occurs as well as pyrite (FeS_2) and chalcopyrite ($CuFeS_2$). The presence of Cd in the mine drainage indicates that greenockite (CdS) might also occur. Greenockite has been found as a coating on sphalerite in Europe (Roberts, 1974). Also, Se (S) or selonite (SeO_2) is the

Table 1. Relative characteristics of drainage from adit Station Numbers13 and 16. Alkalinity, iron, sulfate, and bicarbonate (hardness) concentrations are given in mg/L. Standard deviation is shown.

Parameter	Adit Station Number 13	Adit Station Number 16
pH	2.9 ± 0.2	7.1 ± 0.1
Alkalinity	0	260
Iron	26 ± 1	6.0 ± 0.02
Sulfate	721 ± 23	77 ± 1
Total Hardness	387 ± 4	367 ± 5

inferred source of dissolved Se). Barkesdale (1975) reported that sulfide minerals include pyrite (FeS_2), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and galena (PbS) were present and that the sulfide deposits in the Alder Mine are associated with the host rocks.

Metal Loading

The significance of discharge from abandoned or inactive mine tunnels depends on the metal constituents of the effluent, the toxicity of the particular heavy metals, how much of the metal enters the stream, and whether or not the metal remains in the stream in a toxic form. Although the analytical determination of different solute forms of trace elements in natural waters and soil solutions is largely at a semi-quantitative stage of development the amount of metal entering the stream can be calculated.

The amount of metal entering a stream is called the mass loading. It is calculated as the product of metal concentration and stream discharge. Mass loading estimates for metals in effluent from the two portals studied were compared to mass loading in Alder Creek, which was estimated from the average concentration of metals measured at the sample station nearest the mine outfall (Station 3) and the average of the high- and low-stream flow measurements. The difference between the two was used to indicate the minimum retention of mine discharge constituents by the forest soils.

The estimated sum of total metals (Zn, Ni, Se, Pb, Cu, Cr, and Cd) discharged per year from adits Stations Numbers 13 and 16 was equal to 11,041 kg/yr (Table 2). At station 3, the site closest to the mine outfall, the annual loading is equal to only 886 kg/yr (8% of the total discharged from the adit at Station 13) which is a minimum estimate of the amount of metal delivered to the stream. The retention of at least 90% of the metals discharged conforms to the position taken by Vaughn (1977) that soil is the principal reservoir for the deposition of elements delivered to the environment. Paste pH of the waste-rock below the mine averaged 3.74. Forest soil between the waste-rock and Alder Creek averaged 5.51 and the forest soil not affected by mine waste run-off was 6.44.

Table 2. Annual mass loading (average metal concentration(1) x stream(2) or discharge(3) flow rate) at Alder Mine Station Number 13 and Alder Creek Station Number 3 nearest mine outfall.

Element	Station 3 Near Mine Outfall (kg/yr)	Station Number 13 (kg/yr)
Zn	838	10,205
Ni	0	3
Se	3.93	41.5
Pb	0.6	17
Cu	20	623
Cr	9.5	5.9
Cd	14.4	146
Site Totals =	886	11041

Mass Loading Station 3/Mass Loading Adit 2 = 8%

(1) Average metal concentration, Appendix B

(2) Stream flow rate, Appendix A

(3) Adit flow rate, Huchton
(1997)

Stream Characterization

Dissolved Oxygen and Temperature

Dissolved oxygen, measured on 24 June 1998, ranged from 8.3 to 10.2 mg/L at all sites except site 2 (Table 3), which was 6.8 mg/L. Dissolved oxygen values in excess of 8.0 mg/L meet the freshwater criteria for class A (excellent) surface water in the state of Washington (WAC, 1992). Site 2 at 6.8 ppm dissolved oxygen only exceeds class C (fair) criteria (4.0 mg/L).

The maximum temperature of the stream measured at the station nearest the mine outfall (Station 3) on Alder Creek reached 15.6^0C on three consecutive days August 2-4, 1998 (Appendix A). On Poorman Creek at the mid-reach station (number 11) the maximum stream water temperature measured was 13.2^0C, reached at 1600 hours on 14 August 1998. Temperature values that are less than 18.0^0C meet the freshwater criteria for class A (excellent) surface water in the State of Washington (WAC, 1992).

pH and Alkalinity

The stream water samples from the Poorman Creek reference stream and from Alder Creek were basic and contained high concentrations of bicarbonate. Hydrogen ion concentrations (pH) measured on 24 June 1998 ranged from 8.1 to 8.6 at all sites on both Alder Creek and Poorman Creek (Table 4).

Values for pH that are between the 6.5 to 8.5 meet the freshwater criteria for class AA (extraordinary) surface waters in the state of Washington (WAC, 1992). The pH criteria are the same for all stream water classes. The pH of natural waters ranges from <3.0 to >12.0 and most unpolluted waters exhibit pH values in the range 6.0-9.0 (Davis, 1992). While acid waters are generally characterized by low species diversity and low productivity (Davis, 1992) there appears to be little information available related to the effects on stream water when the pH exceeds 8.5. At all stations, titratable alkalinity was greater than 190 µg/g HCO_3^- (Table 5).

Table 3. Dissolved oxygen concentration in Alder and Poorman Creeks. See Figure 3 for map showing locations of sample stations.

Station	Date	DO (ppm O_2)	Date	DO (ppm O_2)
Poorman Creek				
10	6/24/98	9.4	9/3/98	9.5
11	6/24/98	9.5	9/3/98	9.9
12	6/24/98	9.7	9/3/98	10
Alder Creek				
9	6/24/98	8.8	9/3/98	9.2
1	6/24/98	9.0	9/3/98	7.3
2	6/24/98	6.8	9/3/98	8.6
3	6/24/98	9.2	9/3/98	9.8
4	6/24/98	9.1	9/3/98	9.8
5	6/24/98	9.0	9/3/98	9.6
6	6/24/98	8.4	9/3/98	8.5
Station Number 16	6/24/98	9.1	9/3/98	9.6
Station Number 13	6/24/98	10.7	9/3/98	9.4

Table 4. Alder Creek and Poorman Creek pH. See Figure 3 for map showing sample location.

Site	Date	pH	Date	pH
Poorman Creek				
10	6/24/98	8.1	9/3/98	8.4
11	6/24/98	8.4	9/3/98	8.3
12	6/24/98	8.5	9/3/98	8.3
Alder Creek				
9	6/24/98	8.4	9/3/98	8.3
1	6/24/98	8.6	9/3/98	7.3
2	6/24/98	8.6	9/3/98	7.5
3	6/25/98	8.2	9/3/98	8.2
4	6/25/98	8.4	9/3/98	8.4
5	6/25/98	8.5	9/3/98	8.5
6	6/25/98	8.2	9/3/98	8.1
Station Number 16	6/25/98	7.2	9/3/98	7.1
Station Number 13	6/25/98	3.1	9/3/98	2.8

Table 5. Alkalinity of Alder Creek and Poorman Creek. See Figure 3 for map showing sample stations.

Site	Date	($CaCO_3$ ppm)	Date	($CaCO_3$ ppm)
Poorman Creek				
10	6/25/98	236	9/3/98	268
11	6/25/98	212	9/3/98	236
12	6/25/98	220	9/3/98	221
Alder Creek				
9	6/25/98	190	9/3/98	216
1	6/25/98	360	9/3/98	300
2	6/25/98	194	9/3/98	302
3	6/25/98	242	9/3/98	242
4	6/25/98	276	9/3/98	306
5	6/25/98	265	9/3/98	308
6	6/25/98	242	9/3/98	266
Station Number 16	6/25/98	260	9/3/98	220
Station Number 13	6/25/98	0	9/3/98	0

Current Velocity and Substrate Size

Current velocity ranged from 8 cm/second to 150 cm/second (Appendix A). Stream sediment consisted of small gravel and rubble with particles that ranged in size from 2 to 256-mm intermixed with fine gravel and sand. Large rubble was uncommon. The mean particle sizes at each station were consistent and did not exceed 3 phi units. Percival (1929) described the effect of substrate on fauna and noted that variations in substrate size affected organism density and community structure.

Heavy Metal Concentrations

The physical and chemical forms of trace elements in waters and sediments affect the biological activity of trace elements. Solute trace elements have an assimilation rate that is orders of magnitude greater than the rate from particulate sources (Jenne, 1977). In this study, analytical methods were used to assess both the total and dissolved metal concentrations in water (Appendix B). The average concentration of Cd, Cr, Cu, and Zn (at high flow, n=3) were compared for each station (n=11) using Tuckey's ANOVA and the no significant difference between individual 95% confidence intervals were detected between the concentration of total and dissolved metals (Appendix D).

Zinc (Zn)

The metal at the highest concentration in Alder Creek was Zn at 6,400 μg/ml during high-flow conditions. At this concentration, Zn occurred at a level that was 19 times the water quality criteria (Table 6). The low-flow concentration of Zn was lower at 4369 μg/ml and 12 times the water quality criteria. In Poorman Creek, Zn was not detected. Zn was found to be over criteria at station 5 (1 km downstream from the mine) during high-flow and station 4 (0.5 km downstream) during low-flow (Table 7).

Chromium (Cr)

During high-flow conditions, Cr (72 μg/ml) was lower than Cd at 4.5 times the water quality criteria. During low-flow conditions, however, Cr was unchanged and exceeded criteria at 6.5X and 6.6X respectively (Table 6). Cr levels were only slightly higher than those found in Poorman Creek (i.e., 1.5x) The level of Cr (85 μg/ml) over criteria was relatively constant over all stations and was 5.3 times criteria at station 6 (10 km downstream from mine outfall).

Cadmium (Cd)

The concentration of Cd at 110 μg/ml during high-flow was 6.8 times water quality criteria (Table 6 and 7). Cd concentration and its factor over water quality criteria were essentially unchanged during low flow at 120 μg/ml and 6.5X respectively. Cd in Alder Creek was over 13 times the level found in Poorman Creek.

Table 6. Concentration of dissolved heavy metals (Cd, Cr, Cu, Se, and Zn) in streamwater that exceed Washington State's water quality criteria (WAC 173-201A) at Alder Creek Station 3 nearest mine outfall, their ratio over criteria, and their ratio over average concentrations at Poorman Creek stations 10-12. High-flow samples were collected 6/30/98 and low-flow samples were collected 9/5/98.

HIGH FLOW:

			Ratio:				
	Alder Creek Station (3 μg/ml)	Criteria (μg/ml)	Station 3: Criteria	Station 3: Stations 10-12	Station 3: Station 9	Poorman Creek (Stations 10-12): Criteria	Station 9: Criteria
Zinc	6399.8	329.4	19.4	NR[1]	NR	NR	NR
Selenium	30.0	20.0	1.5	1.5	1.5	1.5	1.5
Cadmium	107.1	15.7	6.8	NR	NR	0.6	NR
Chromium	71.6	16.0	4.5	1.5	1.5	3.3	2.9
Copper	148.3	54.9	2.7	NR	NR	NR	NR

LOW FLOW:

			Ratio				
	Alder Creek Station (3 μg/ml)	Criteria (μg/ml)	Station 3: Criteria	Station 3: Stations 10-12	Station 3: Station 9	Poorman Creek (Stations 10-12): Criteria	Station 9: Criteria
Zinc	4368.8	369.4	11.8	NR	NR	NR	NR
Selenium	267.7	20.0	13.4	9.3	9.3	1.5	8.2
Cadmium	119.1	18.3	6.5	13.0	13.0	0.5	0.5
Chromium	105.1	16.0	6.6	1.4	1.2	4.8	5.9
Copper	1.3	62.4	<1	0.0	0.0	NR	NR

(1) NR = No ratio where denominator (reference concentration) was equal to zero

Table 7. Farthest station downstream from mine outflow where dissolved metal concentrations exceed Washington State's water quality criteria (WAC 173-201A).

	Station Number (Distance Below Mine Outfall)	
	High Flow	Low Flow
Zinc	5 (1 km)	4 (0.5 km)
Selenium	6 (10 km)	6 (10 km)
Cadmium	4 (0.5 km)	4 (0.5 km)
Chromium	6 (10 km)	6 (10 km)
Copper	3 (0 km)	Above Criteria at all Stations

<u>Copper (Cu)</u>

Cu exceeded water quality criteria during high-flow conditions (2.9X at 148µg/ml). In contrast, Cu was significantly less than the criteria level during low-flow conditions (0.2X at 1.3 µg/ml). Cu was not detected in Poorman Creek during high- or low-flow sampling.

<u>Selenium (Se)</u>

Se was only 1.5 times the criteria level during high-flow conditions. At 30 µg/ml, the amount measured was at the limits of detection by ICP-MS analysis. During low-flow, however, Se levels increased to over 13 times criteria levels and was still over 11 times the criteria level at station 6 (10 km downstream from mine outfall). Estimated background levels of Se at Poorman Creek Stations 10-11 and Alder Creek reference Station 9 was 1.5 times criteria during low-flow conditions. During high-flow, the ratio at Station 9 increased to 8.2.

Relative Metal Concentrations, Mobility, and Changes over Time in Streamwater

The order of metal concentrations over criteria can be ranked as Zn (19.4x) > Se (13.4x) Cd (6.8x) ≅ Cr (6.6X) > Cu (2.7X). These results greatly exceed the potential hazard from Cd which was estimated to be present at 2.5 times water quality criteria (Huchton, 1995).

The ranking of Zn, Cd, Cu, and Se, based on the distance downstream at which they fall below criteria (Table 7), is Se (10 km) > Zn (1 km) > Cd (0.5 km) > Cu (0 km). While the relative order of Zn and Cd mobility is consistent with the order of their concentration over background levels, Se, at levels between 30 and 268 ug/ml, appears to potentially impact the largest area including the rearing ponds that harbor juvenile salmonids at the confluence of Alder Creek and the Methow River. Hermanutz (1991) showed that Se, when present in the water of a natural ecosystem at 10 μg/ml, may adversely affect bluegills. When the ratio of the concentration of metals in Alder Creek to their concentration at reference stations is considered, Se and Cr are elevated at the lowermost stations (number 6, 10-km below mine outfall) on Alder Creek.

While it has been shown in studies that there is a dependence of trout on terrestrial insects, it has also been shown that there is a significant dependence of fish on aquatic organisms (Vaughn, 1977). Mayfly nymphs (i.e., *Baetis*) were found to be most important and it was reported that benthic organisms in the Upper Clark Fork River were implicated as a dietary source of metals that may be a chronic problem for young-of-the-year rainbow trout. Hilton et al. (1980) showed that dietary Se was highly toxic to trout. Hodson (1980) attributed the death of fish in a North Carolina reservoir to the food-chain accumulation of Se in water where solute water concentrations were low.

Chemical processes are responsible for the relative mobility of metal ions, their attenuation by organic and inorganic substances, and their ultimate concentrations in surface waters and sediments. In studies on the mobility (or conversely attenuation) there is experimental evidence that indicates the relative order of mobility for the metals discussed above is Cd > Zn > Cu (Sidle, 1991; Kelley, 1997). In these studies, the mobility of Cu is consistent with that observed at Alder Creek.

Zinc, present at nominally higher levels than Cd, may exhibit greater mobility in the Alder Creek system (5-km versus 4-km respectively during high-flow). Paulson (1996) presented evidence that supports this possibility. It was observed that the order in which metals in the surface waters of Moon Creek and the lower Coeur d'Alene River were scavenged was Cu > Zn = Cd. Data on the mobility of Se was not included in these studies. The concentrations of Zn, Cd, Cu, and Se in streamwater relative to Poorman Creek and to Washington State water quality criteria are shown in Figures 6-9 respectively.

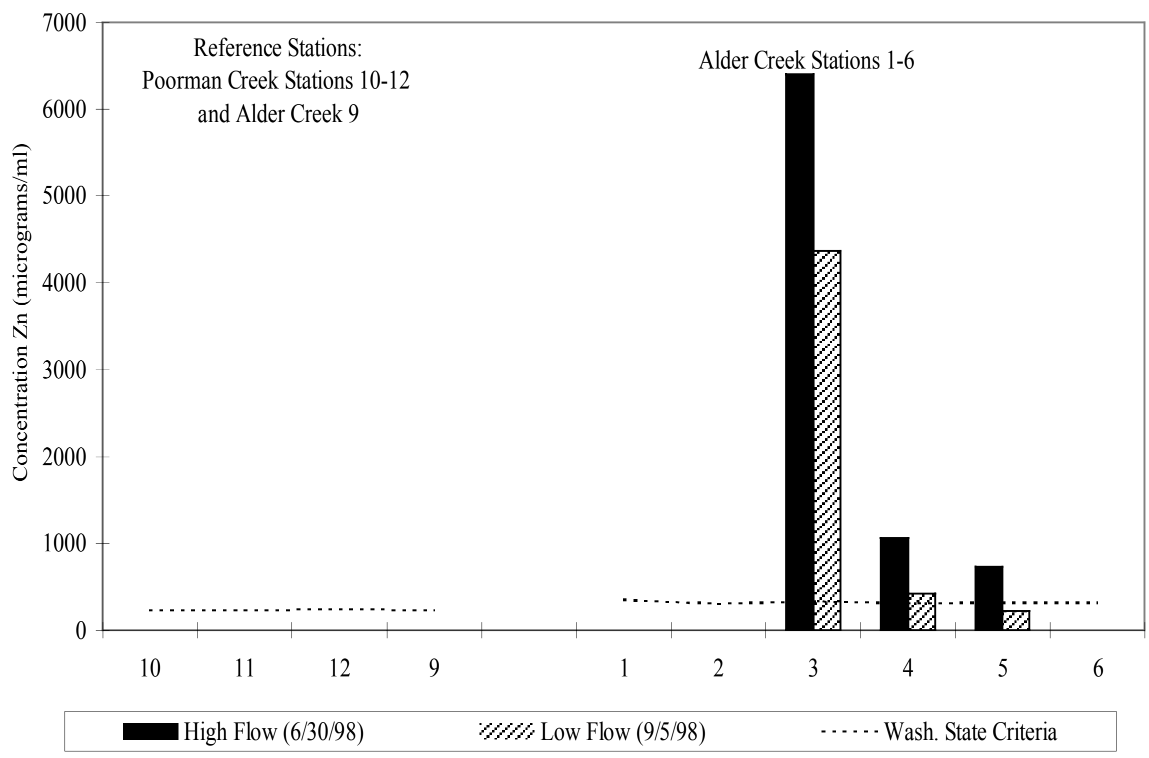

Figure 7. Concentration of zinc in streamwater at high-flow (6/30/98) and at low-flow (9/5/98) in relation to water quality criteria (WAC173-210A).

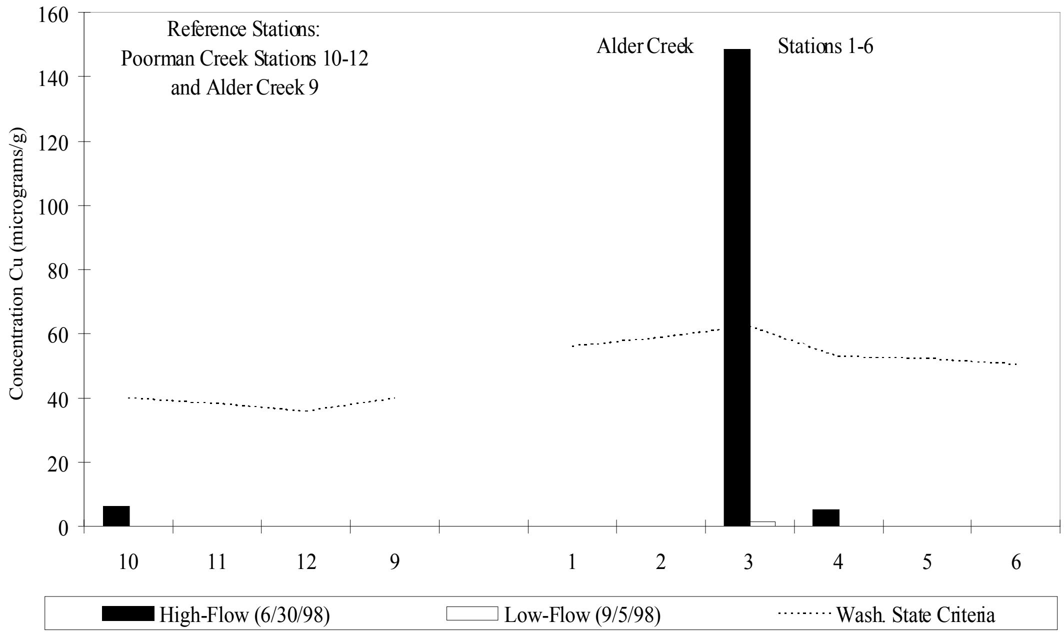

Figure 8. Concentration of Cu in streamwater at high-flow (6/30/98) and at low-flow (9/5/98) in relation to water quality criteria (WAC 173-210A).

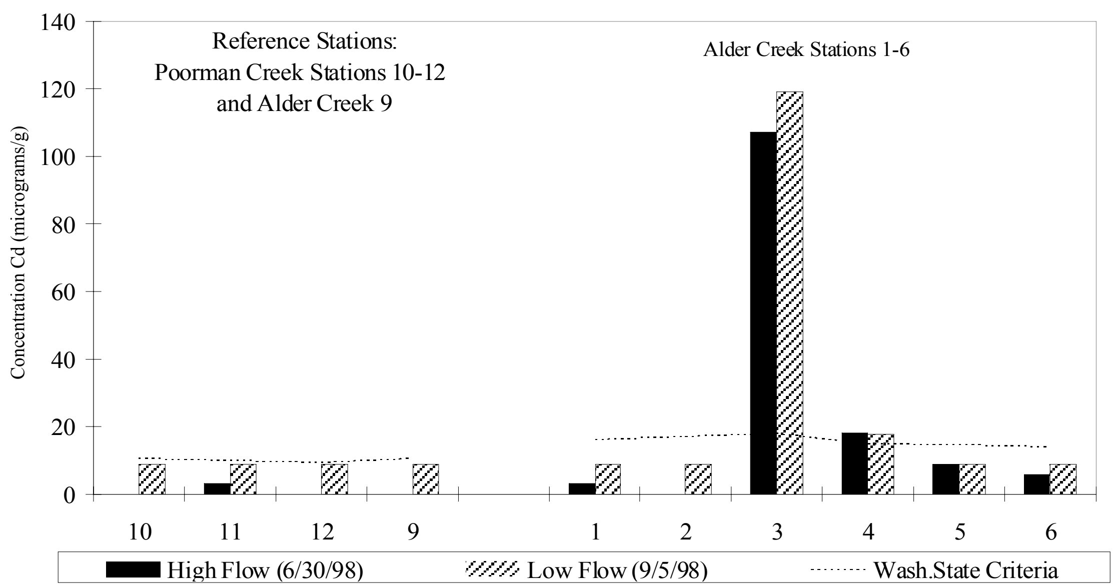

Figure 9. Concentration of Cd in stream water at high-flow (6/30/98) and at low-flow (9/5/98) in relation to Washington State water quality criteria (WAC 173-210A).

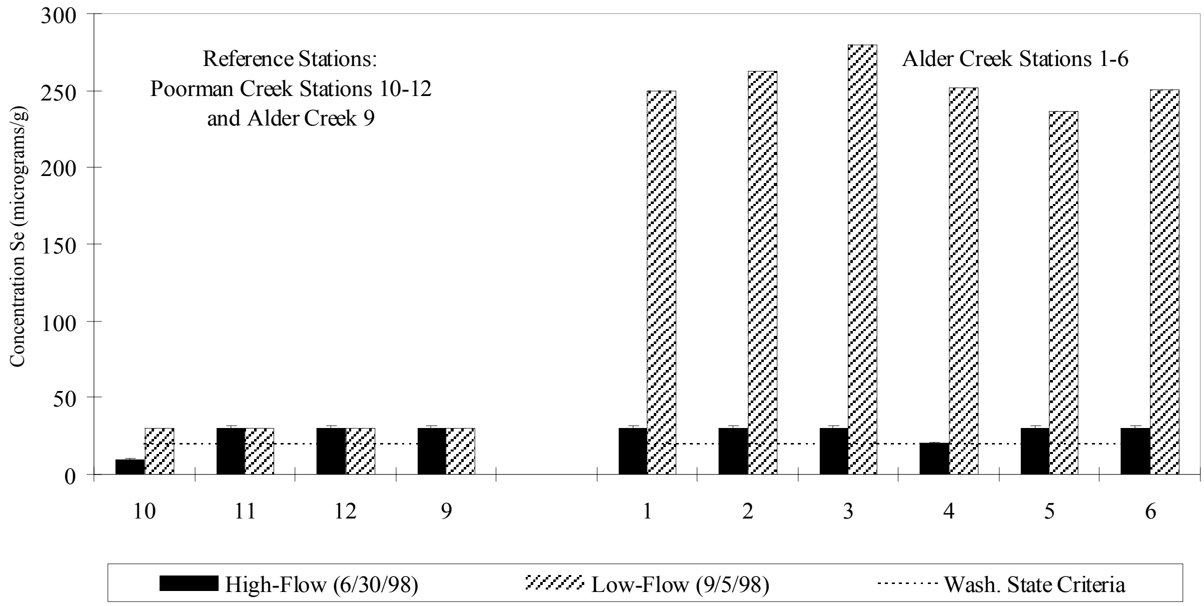

Figure 10. Concentration of Se in streamwater at high-flow (6/30/98) and at low-flow (9/5/98) in relation to water quality criteria (WAC 173-210A).

When the concentration of metals in Poorman Creek are considered, it can be seen that Cr occurs at levels as high as 4.8 times water quality criteria (Table 6). At station 9 on the Alder Creek tributary away from the mine, Se occurred at 8.2 times (163 µg/ml) the criteria level and was nearly as high (65%) as the levels found at Alder Creek Stations 1 and 2 which are below the mine waste-rock and Alder Creek Stations 3-6 that are located below the mine effluent outfall (> 250 µg/ml at Stations 1-3). Selenium, therefore, may occur at elevated levels during low-flow conditions as a result of local mineralization and hydrology. The enrichment of streamwater by Se during the low-flow period may, in turn, be accentuated in Alder Creek Stations 1-6 by processes occurring in the waste-rock above the creek.

Information on local geology and geochemistry is, therefore, important to establish reasonable baseline conditions for metals in water. Kelley (1997) showed that Al, Fe, Mn, Cd, Co, Cu, Ni, Pb, and Zn were present in water associated with highly mineralized deposits at concentrations many times greater than in water from an area where the extent of exposure to mineralized deposits, the grade of mineralization, and the presence of carbonate rocks are different. This is an important consideration in relation to the subject of remediation where it would be more cost-effective and technologically feasible to remediate a mine site to background levels that existed before mining rather than to remediate water to standards that are lower than local natural background concentrations.

There was a similar profile for the seasonal variability in the concentrations of Zn and Cd in Alder Creek (Figures 11 and 12). Cd and Zn declined by over one order of magnitude from maximum levels to minimum levels for five weeks following high flow then recovered to near maximum levels by week 6 following high flow and remained at those levels until the end of the study. Copper declined to zero by week 5 (Figure 13) and remained at that level until the end of the study. Selenium was low although above the freshwater criteria until low-flow samples were taken in September when the concentration increased to substantially higher levels (Figure 14).

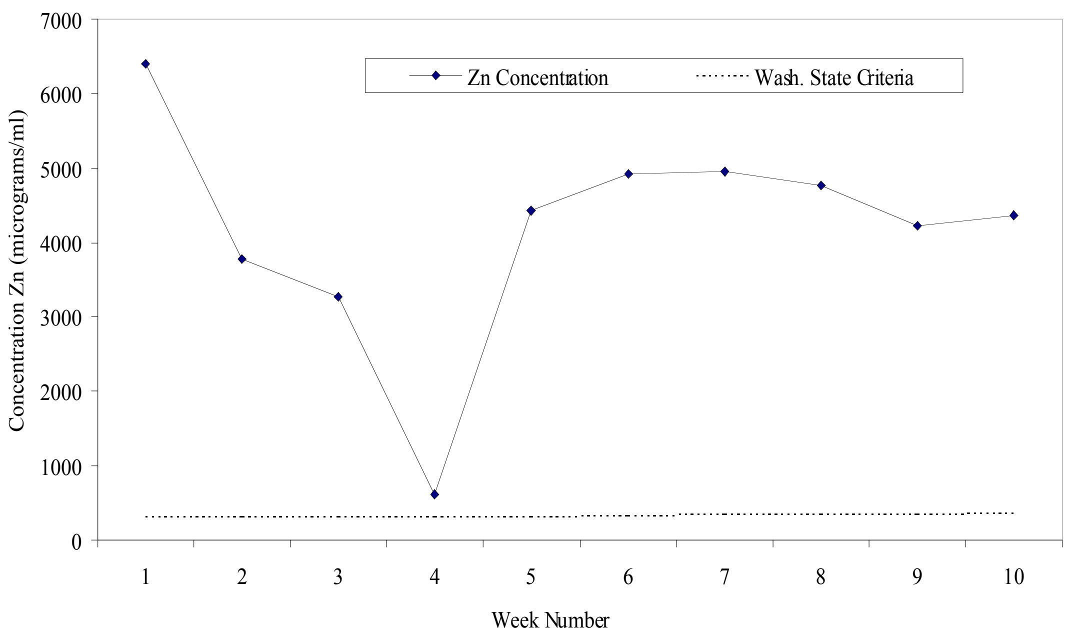

Figure 11. Time trend for Zn concentration in relation to water quality criteria (WAC 173-201A) at Station 5 near mine outfall between high-flow (6/30/98 = week 1) and low-flow (9/5/98 = week 10).

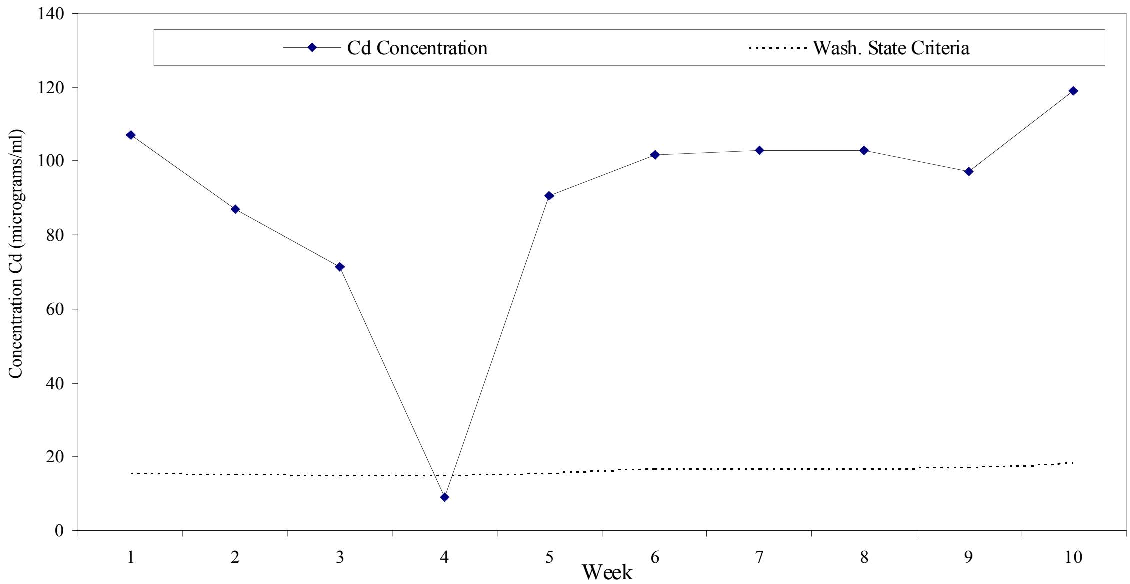

Figure 12. Time trend for Cd concentration at Station 3 near mine outfall between high-flow (6/30/98) and low-flow (9/5/98).

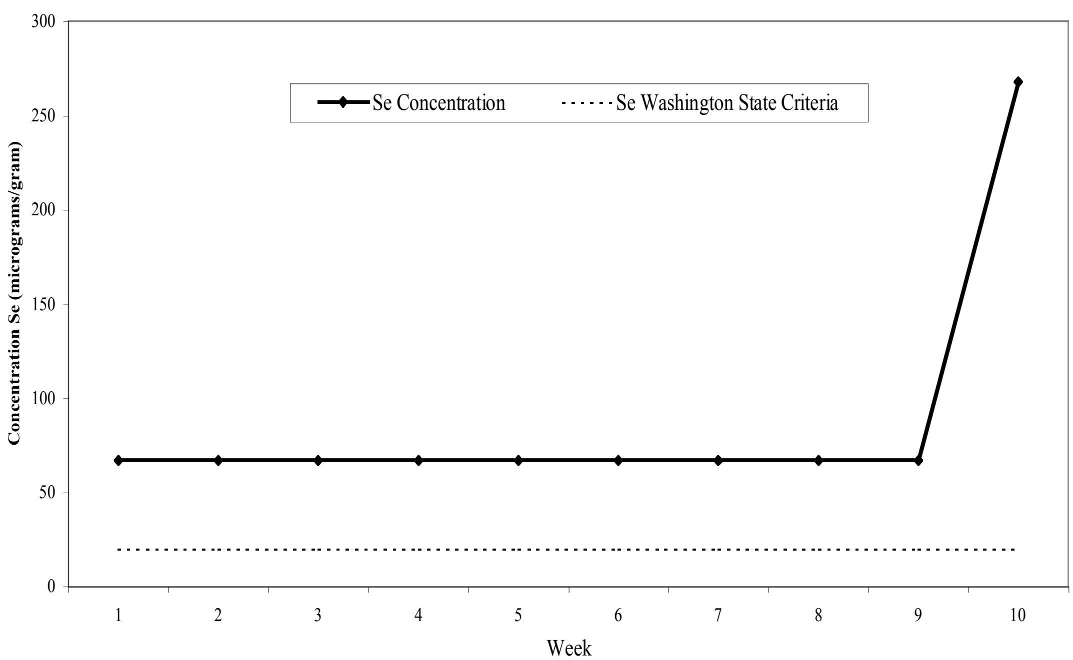

Figure 13. Time trend for dissolved Se concentration in relation to water criteria (WAC 173-201A) at station 3 near mine outfall between high-flow (6/30/98 = week 1) and low-flow = week 10).

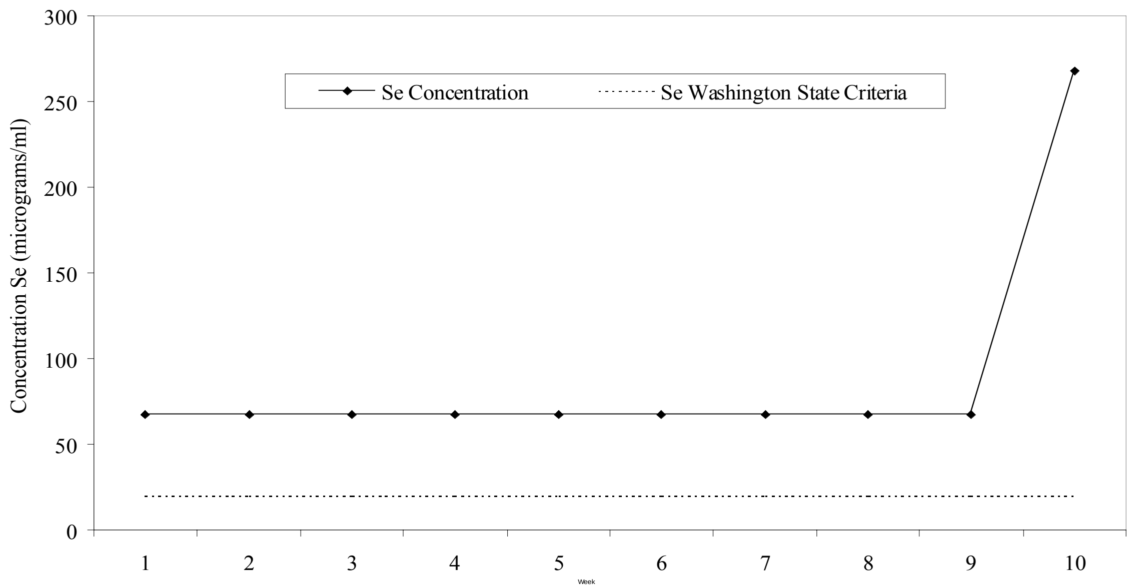

Figure 14. Time trend for dissolved Se concentration in relation to criteria (WAC 173-201A) at station 3 near mine outfall between high-flow (6/30/98 = week 1) and low-flow = week 10).

Sediment Chemistry

Stream sediments act as sinks for the accumulation of heavy metals discharged into surface waters and trace elements in sediments are a source of metals for invertebrates that ingest particles. However, even when metal concentrations in sediments are high and exceed background levels, metal bioavailability can be minimal and adverse impacts may not occur. Nevertheless, the nominal level of metals in sediments and their concentrations relative to estimated background levels were evaluated (Appendix B) in terms of the process of sediment metal enrichment.

Zinc (Zn)

The sediment metal at the highest concentration in Alder Creek was at station 3 near the mine outfall where Zn was present at over 17 times criteria (Table 8) during both high- and low-flow sampling periods (7021.0 and 7290.1 μg/g respectively). The concentration of Zn in Alder Creek sediments was 77 times the average level found in Poorman Creek (Table 8) and over 40 times the level at the Alder Creek reference station 9. Zn was over sediment criteria 1-km downstream (station 5) from the mine outfall in both high- and low-flow samples (Table 9).

Table 8. Concentration of heavy metals (Cd, Cr, Cu, Se, and Zn) in sediments that exceed Washington State's sediment quality criteria (WAC 173-204-320A) at Alder Creek Station 3 nearest mine outfall, their ratio over criteria, and their ratio over average concentrations at Poorman Creek stations 10-12. High-flow samples were collected 6/30/98 and low-flow samples were collected 9/5/98.

HIGH FLOW:

			Ratio		
	Alder Creek Station (3 μg/g)	Criteria (μg/g)	Ratio Station 3: Criteria	Ratio Station 3: Stations 10-12	Ratio Station 3: Stations 9
Zinc	7021.0	410.0	17.0	<1	42.0
Cadmium	95.1	5.1	18.6	11.0	13.0
Chromium	14.0	260.0	< 1	<1	<1
Copper	283.7	390.0	< 1	14.0	9.0

LOW FLOW:

			Ratio		
	Alder Creek Station (3 μg/g)	Criteria (μg/g)	Ratio Station 3: Criteria	Station 3: Stations 10-12	Ratio Station 3: Stations 9
Zinc	7290.1	410.0	17.8	77.0	44.0
Cadmium	45.9	5.1	9.0	5.0	5.0
Chromium	20.8	260.0	< 1	< 1	< 1
Copper	103.1	390.0	< 1	5.0	2.0

Table 9. Farthest station downstream from mine outflow where metal concentration exceeds Washington State's sediment quality criteria (WAC 173-204-320A).

	Station Number (Distance Below Mine Outfall)	
	High Flow	Low Flow
Zinc	5 (1 km)	5 (1 km)
Cadmium	6 (10 km)	6 (10 km)
Chromium	Above Criteria at all Stations	Above Criteria at all Stations
Copper	3 (0 km)	Above Criteria at all Stations

Cadmium (Cd)

The concentration of Cd at 95.1 μg/g during high-flow was 8.6 times sediment quality criteria (Table 8). The concentration of Cd and the factor at which it exists over sediment quality criteria during low-flow were lower at 45.9 μg/g and 9X respectively. Alder Creek station 3 at mine outfall was enriched by a factor of 5X over Poorman Creek stations 10-12 and Alder Creek station 9. Cd levels remained over criteria 10-km downstream (station 6; Table 9).

Chromium (Cr) and Copper (Cu)

Cr and Cu were below sediment quality criteria at all stations during both high- and low-flow sampling periods. They were, however, elevated in relation to Poorman Creek stations 10-12 and Alder Creek station 9 by factors equal to 14x and 9x respectively during high-flow and 5x and 2x during low flow.

<u>Relative Metal Concentrations, Mobility, and Changes over Time in Stream Sediments</u>

Sediment metal concentrations are given in Appendix B and the ratio of the maximum observed concentrations (Station 3) to sediment quality criteria is given in Table 8. Based on these results, the metals can be ranked as follows: Cd (19x) ≅ Zn (17x) during high-flow and Zn (18x) > Cd (9x) during low-flow.

When the results for Cd, Zn, Cu, and Cr are evaluated based on the distance downstream from the site nearest the mine outfall that they exceed water quality criteria, the metals can be ranked as follows: Cd (10 km) > Zn (5 km). Copper and Cr did not exceed the sediment criteria in Alder Creek. The sediment concentrations of Zn, Cd and Se relative to Poorman Creek and to the applicable Washington State sediment quality criteria are shown in Figures 15-17. There are no criteria for Se in sediments and the maximum detected concentration of Se (519 ug/g) was approximately 2 times that found in Poorman Creek.

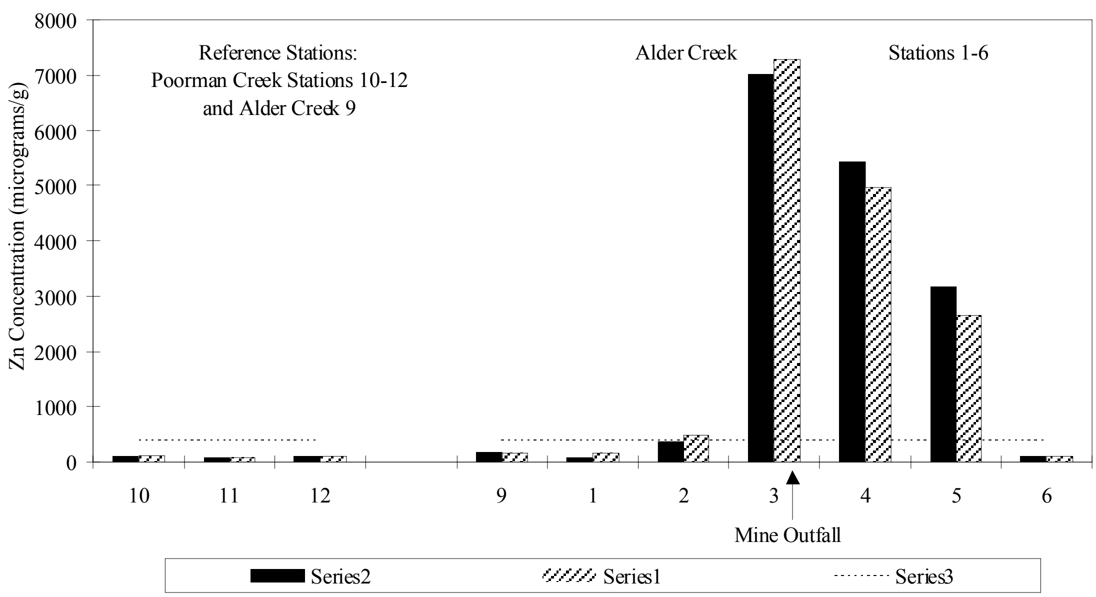

Figure 15. Concentration of Zn in sediments at high-flow (6/30/98) and low-flow (9/5/98) in relation to Washington State sediment quality criteria (WAC 173-204-320A)

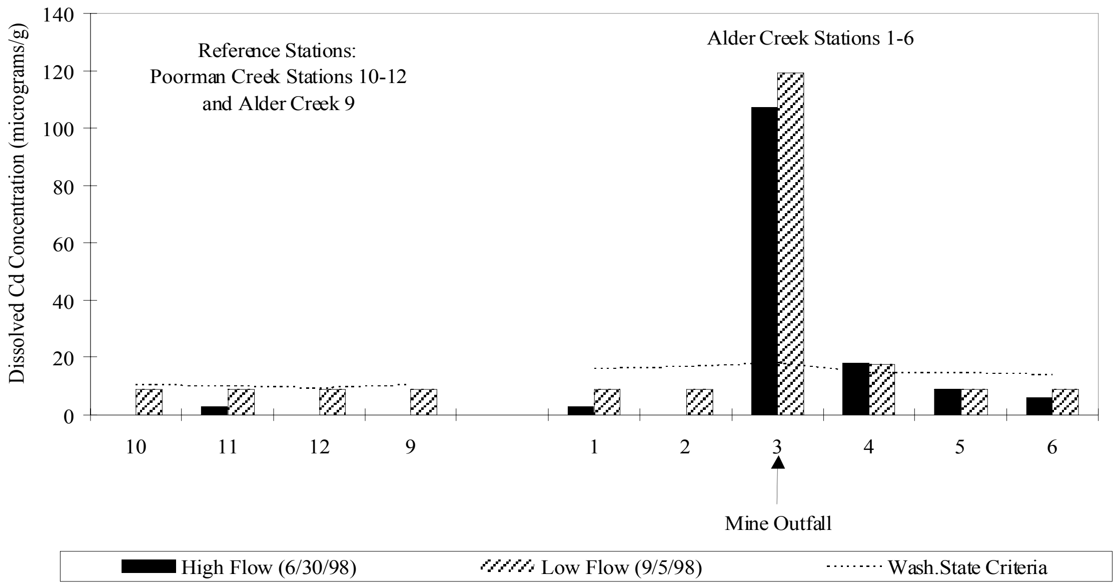

Figure 16. Concentration of dissolved Cd in sediments at high-flow (6/30/98) and at low-flow (9/5/98) in relation to sediment criteria (WAC 173-210A).

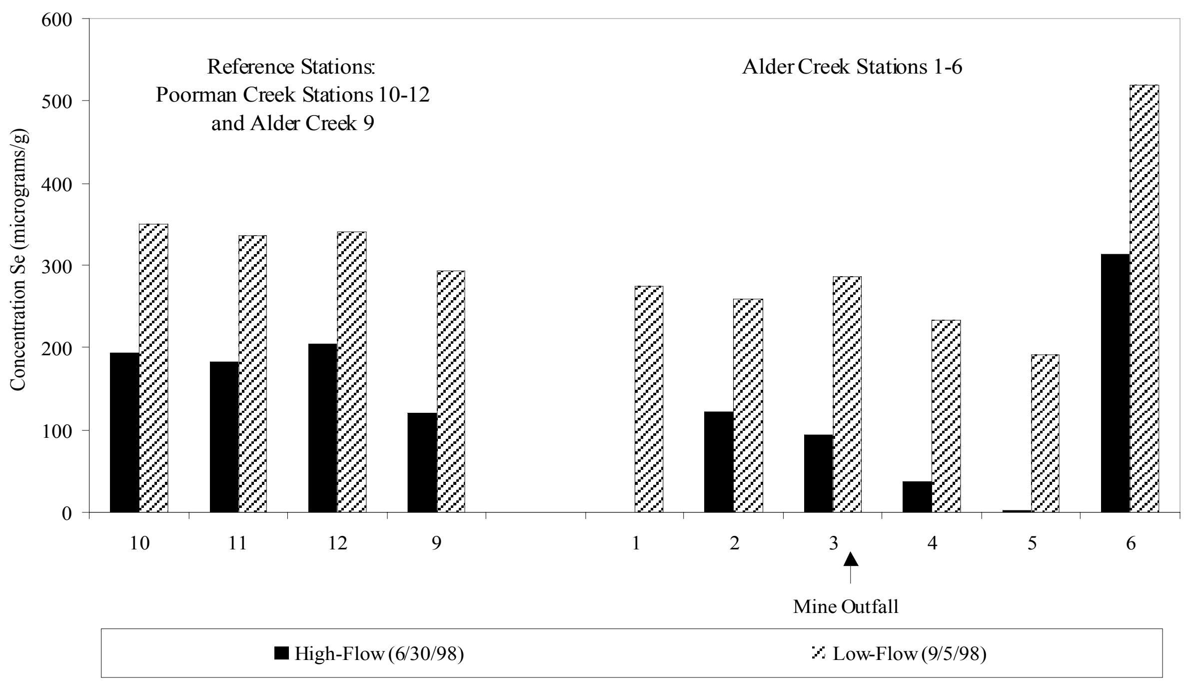

Figure 17. Concentration of Se in stream sediments at high-flow (6/30/98) and low-flow (9/5/98).

QA/QC

Field blanks were below detectable limits for all metals analyzed by ICP-MS. Laboratory spikes were within 5% of certified concentrations. Field spikes were greater than 5%. Repeat samples to determine the source of the error revealed that the known water contained 5% HNO_3 and when preserved in the field with 0.15% HNO_3 totaled 5.15% HNO_3. The additional 5% HNO_3 was determined to be responsible for the error greater than $\pm$ 5%.

Stream Biology

Benthic Community Response to Heavy Metals

In communities there are, typically, a few genera represented by large numbers of individuals, smaller numbers of several genera, and many genera that are represented by a few individuals (Appendix C). Figure 18 depicts the benthic community structure of the reference sites on Poorman Creek. A graph of the Alder Creek benthic community structure is given in Figure 19. A comparison of the community structure of the reference stations to that of the station nearest the mine outfall is given in Figure 20. Rare or infrequently occurring taxa were not included in Figures 18-20.

Forty-eight (48) taxa were collected during this investigation. Ephemeroptera (8genera, 19%), Plecoptera (10 genera, 24%), and Trichoptera (10 genera, 24%). The unpolluted stations yielded the greatest number of taxa (42). Collectively, the stations below the mine outfall contained 28 taxa Plecoptera (8 genera, 28%) and Trichoptera (6 genera, 21%) dominated the community. The station nearest the mine outfall (Station 3) contained the least number of taxa (8). Ephemeroptera was less common (3 taxa, 10%), Diptera and Coleoptera contained 7 taxa (24%).

The taxa identified as the top five based on overall abundance (i.e., *Baetis,* Simulidae, *Cinygmula,* Chloroperlidae, *Heterlimnius,* and *Zapada*) over all sites sampled can be found at any given site although not always in the same order. These taxa, therefore, can occur over the range of physicochemical characteristics although the relative abundance of these taxa can differ between sites.

Cinygmula was the second most abundant taxa of 48 taxa identified in Poorman Creek and in Alder Creek it was the second least abundant out of 28. Of the other dominant taxa in Poorman Creek, *Baetis,* Chloroperlidae, *Heterlimnius,* and Chironomidae were reduced by at least 50% in Alder Creek but remained the same in relative importance. Out of the 48 taxa found in Poorman Creek, 17 taxa (35%) were absent from Alder Creek. Simulidae, which occurred infrequently in Poorman Creek, was the dominant taxa in Alder Creek.

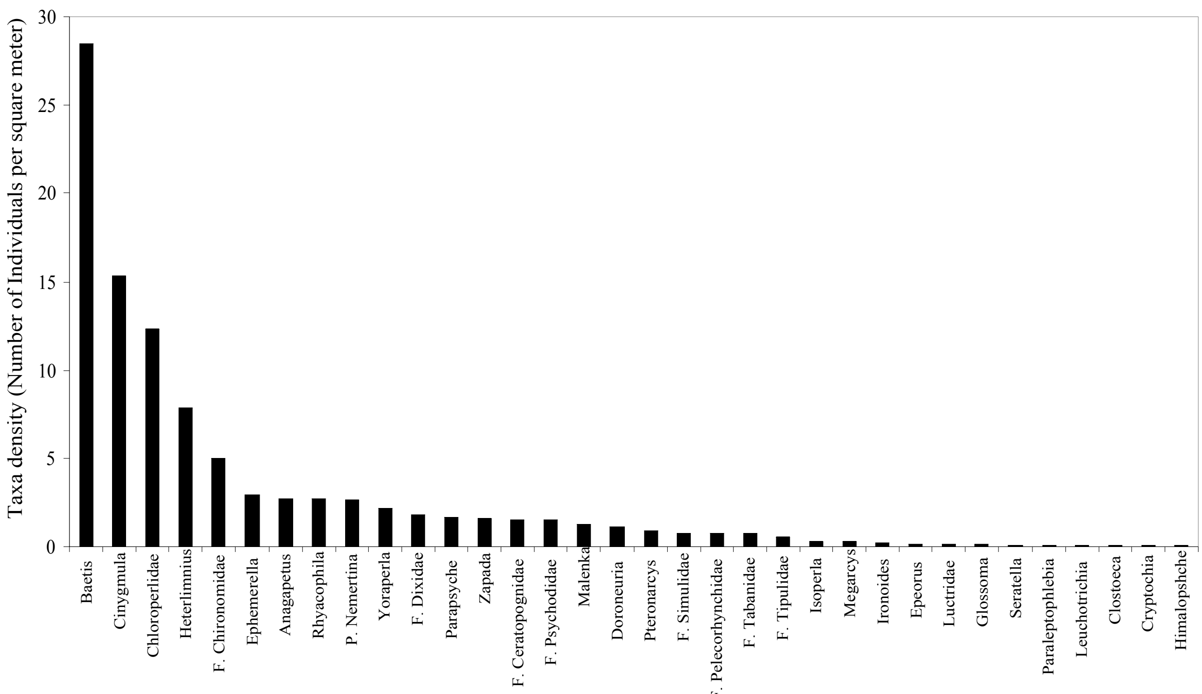

Figure 18. Community structure of Poorman Creek. Taxa are ranked in descending order based on average density per square meter from Surber samples taken at reference stations 9-12.

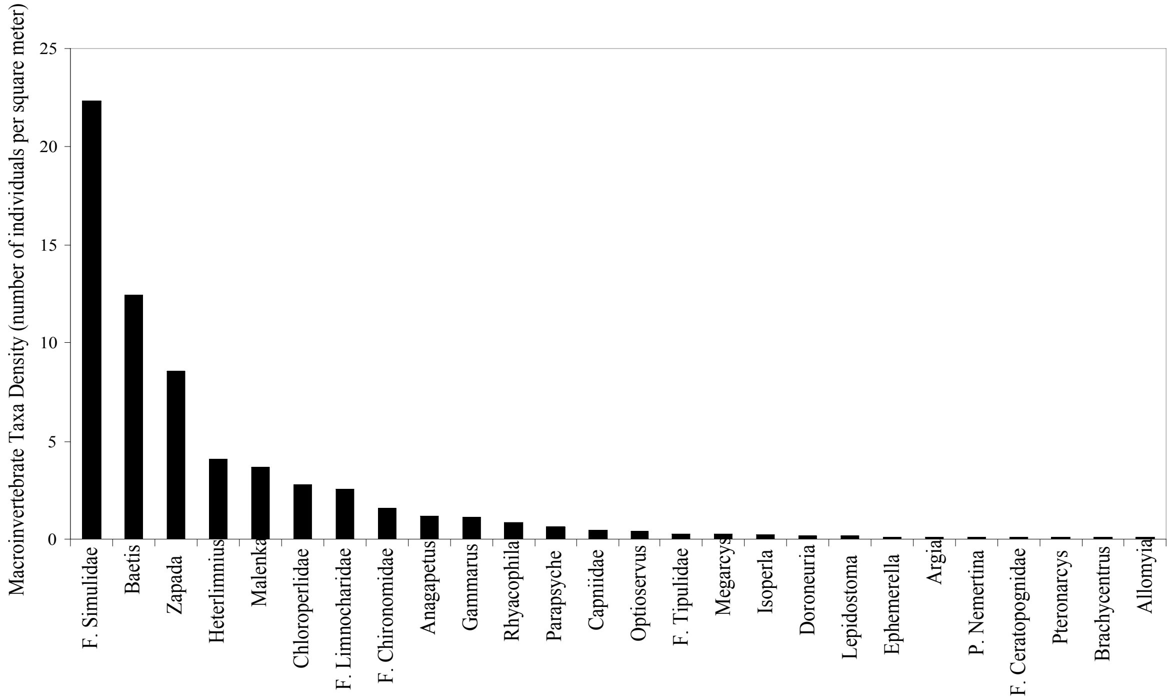

Figure 19. Community structure of Alder Creek. Taxa are ranked in descending order based on average density per square from Surber samples taken at stations 3-6.

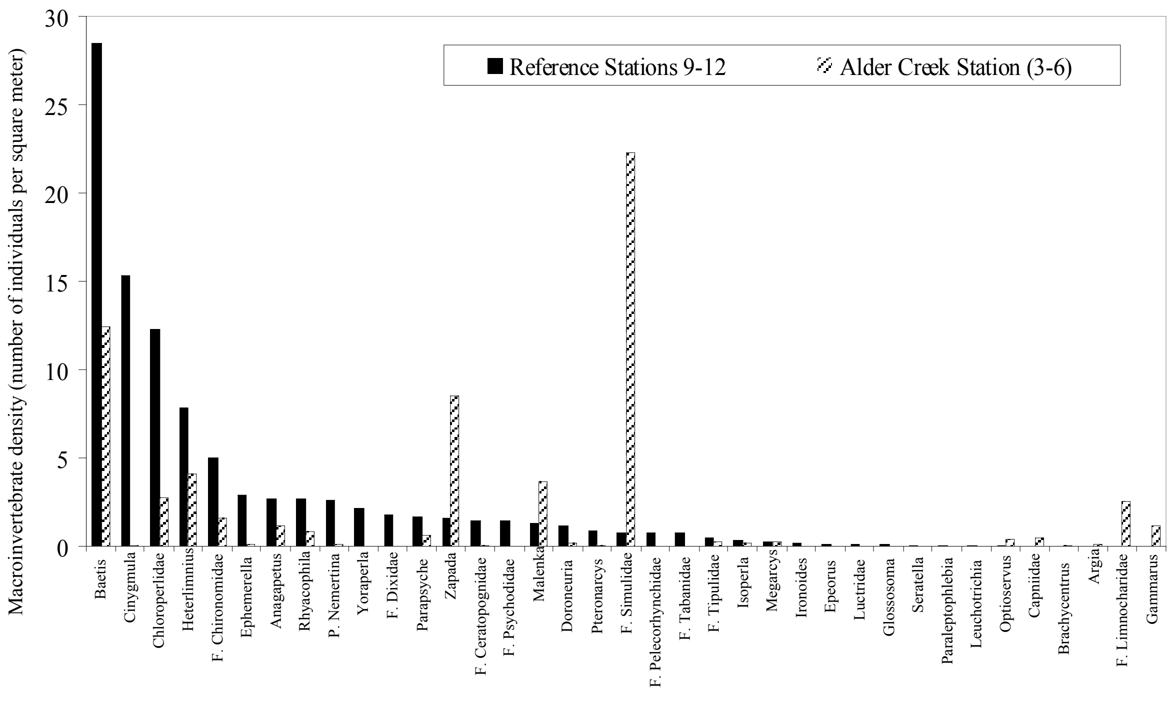

Figure 20. Density of Alder Creek taxa at Station 3 near mine outfall in relation to the community structure of Poorman Creek.

The three dominant taxa in Poorman Creek (i.e., *Baetis, Cinygmula,* and Chloroperlidae) are from the orders Ephemeroptera and Plecoptera and are considered collectors, scrapers, and predators respectively (Montana DEQ, 1996). In Alder Creek the three dominant taxa (i.e., Simulidae, *Baetis,* and Zapada) are from the orders Diptera, Ephemeroptera, and Plecoptera respectively and are considered to be filterers, collectors, and shredders. Scrapers and predators, therefore are replace by shredders and collectors in Alder Creek below the mine. This contradicts Scheiring (1993) who reported that there were no shredders or collectors found in the active mine stream studies.

The benthic fauna community structure and the concentration of heavy metals indicate that elevated levels of Cd, Se and Zn might exert the greatest influence on Ephemeropterans (reduced from 17% to 10% of total). Although the occurrence of *Baetis* and *Cinygmula* was reduced, these two genera appear to be somewhat tolerant of metal pollution and were found to persist at low levels in the presence of heavy metals. Chapman and Demory (1963) observed that Ephemeroptera (e.g., *Ephemerella*) were the most sensitive to all metals. In this study, the dominant Mayfly was *Baetis* whereas *Ephemerella* was only rarely encountered. The density of *Baetis* was reduced from over 170 individuals/m^2 to less than 80 individuals/m^2.

Simulidae, which occupied a minor place in the community of the unpolluted stations appeared to be a tolerant opportunist and was the most abundant organism below the mine outfall. The species composition was distinctly different at the polluted and non-polluted stations. Other studies have reported similar results (Wellnitz, 1994) where macroinvertebrate communities were depauperate as a result of high levels of metals.

A one-way ANOVA (Tukey's Comparison Test) was conducted to compare values for abundance, taxa richness, EPT index, and Karr's 5-Metric Benthic Index of Biotic Integrity, the Shannon-Wiener Diversity Index, and the ICS (Perrish, 1983), from Alder Creek stations below the mine outfall (Stations 3-6) with reference stations 9-12. Triplicate samples from the four sites on each creek were collected on 31 June 1998, and on 5 September 1998 (n=24). Average abundance of invertebrates and taxa richness was significantly different ($P<0.001$) between the Alder Creek stations below the mine and the reference stations. *Baetis,* Ephemeroptera, Average EPT, taxa richness, ICS, and Karr's 5-Metric B-IBI index values were also significant ($P\leq 0.005$).

Based upon this analysis, the benthic community structure at all stations was meaningfully different at the 5% level of significance. It was clearly demonstrated that the contamination of Alder Creek with mine effluent has had a measurable impact on the community structure of the benthic macroinvertebrates.

Integration of Chemical and Biological
Indicators of Heavy Metal Pollution

The chemical impact of acid mine drainage on Alder Creek and the effects to the benthic community structure conforms most closely to the Case II category of problems (Hodson, 1990) which are related to chemical contamination where the metals have been detected but the ecological effects are not obvious. Cd, Cr, Cu, Se and Zn were shown to exceed Washington State's criteria for water and sediments, are high relative to reference stream results, and are suggested as possible causes of environmental degradation in Alder Creek. Based upon the biological analyses performed, the benthic community structure at all stations was meaningfully different at the 5% level of significance. The reduced diversity levels and impacts on community structure, reflected in the 5-Metric B-IBI, suggest a chemical etiology related to the contamination of Alder Creek with mine effluent.

Other possible cause-effect relationships, however, are possible. If the chemical and biological data are evaluated using epidemiological criteria (Fox, 1989) a strong relationship between the heavy metals from the mine effluent and the changes in benthic community structure can be claimed.

Since data were not collected in the stream when chemicals were not present, it was necessary to evaluate the biological data relative to a closely matched reference population. For example, in Alder Creek the measures of taxa richness and the differences in taxa composition in the benthic community was dramatic relative to those found in Poorman Creek.

Knowing the possible cause of the changes in taxa richness and community structure, a literature search for experimental data on heavy metal toxicity and the response of benthic macroinvertebrates was conducted. Based on the work of Kiffney et al. (1996, 1994), Surber, (1936), Schering (1993), Rasmussen et al. (1988), Wellnitz (1994), Cairnes et al. (1971), Nelson (1994), Bissonette (1977), and Barcelo et al. (1990) the association of heavy metals with changes in benthic community structure is well established. It appears from the data acquired that indicators at various levels of organization including populations (e.g., abundance or density per square meter) and community (e.g., diversity and dominance) indicate metals are affecting the community structure of benthic fauna in Alder Creek.

If most of the dissolved metals in Alder Creek are derived from the abandoned Alder mine, the concentrations of metals are affected by dilution from groundwater and by sorption, and if there is a strong dose-response relationship between the concentration of heavy metals and invertebrate response, then there should be a correlation between distance, metal concentration, and biological indicators.

Regression models were used to test the effects of distance from mine outfall on Alder Creek and metal concentration on *Baetis,* Ephemeroptera number, EPT richness, BIBI, abundance, taxa richness, Index of Community Sensitivity (ICS; Parrish, 1983), and Shannon-Wiener Diversity Index. According to the regression models, a positive correlation was observed for all parameters (Table 10) and stream location and metal concentration at stations on Alder Creek except for the EPT Index, the Shannon-Wiener

Index, and the ICS (P>0.1). Rasmussen and Lindegaard (1988) found a negative correlation between numbers of taxa and the concentration of dissolved iron.

Table 10. Sample size (n), coeffecient of determination (r^2), and confidence level (p) for regression models used to test effects of distance along longitudinal gradient and gradients of metal concentration on invertebrate community metrics.

	Alder Creek x Distance			Alder Creek x Metals			Poorman Creek x Distance		
	n	r^2	p	n	r^2	p	n	r^2	p
Abundance	3	0.351	0.01	3	0.177	0.082	3	0.523	0.001
Taxa Richness	3	0.368	0.008	3	0.485	0.001	3	0.274	0.026
Baetis	3	0.527	0.001	3	0.293	0.02	3	0.513	0.001
Ephemeroptera	3	0.527	0.001	3	0.293	0.02	3	0.628	0
EPT Richness	3	0.136	0.133	3	0.620	0.317	3	0.430	0.409
5-Metric BIBI	3	0.344	0.011	3	0.300	0.019	3	0.333	0.012
Metals	3	0.741	0	3	NA	NA	3	NA	NA

<u>Potentially Confounding Parameters: Benthic Community Response to Longitudinal Gradient</u>

Regression models were also used to test the effects of stream location on *Baetis,* Ephemeroptera number, EPT richness, BIBI, abundance, taxa richness, Index of Community Sensitivity (ICS; Parrish, 1983), and Shannon-Wiener Diversity Index at stations on Poorman Creek. According to the regression models, these indicators were also correlated with distance downstream as they were in Alder Creek (Figures 21-25). A negative correlation was observed for all parameters (P<0.05) and stream location except for the metal concentration, EPT Index, the Shannon-Wiener Index, and the ICS (P>0.1). It appears that the benthic communities of macroinvertebrates, responding to longitudinal gradients (Minshall et al., 1985), could be responsible for the positive correlation of community metrics in Alder Creek with distance from the mine.

Because the community structure of benthic macroinvertebrates varies widely with chemical, physical, and environmental conditions a stepwise regression was performed on the data to test for the effects of streamflow, dissolved oxygen, alkalinity, mean substrate particle size, sediment and water pH, and water temperature on taxa richness. It was shown that these parameters were not correlated with diversity.

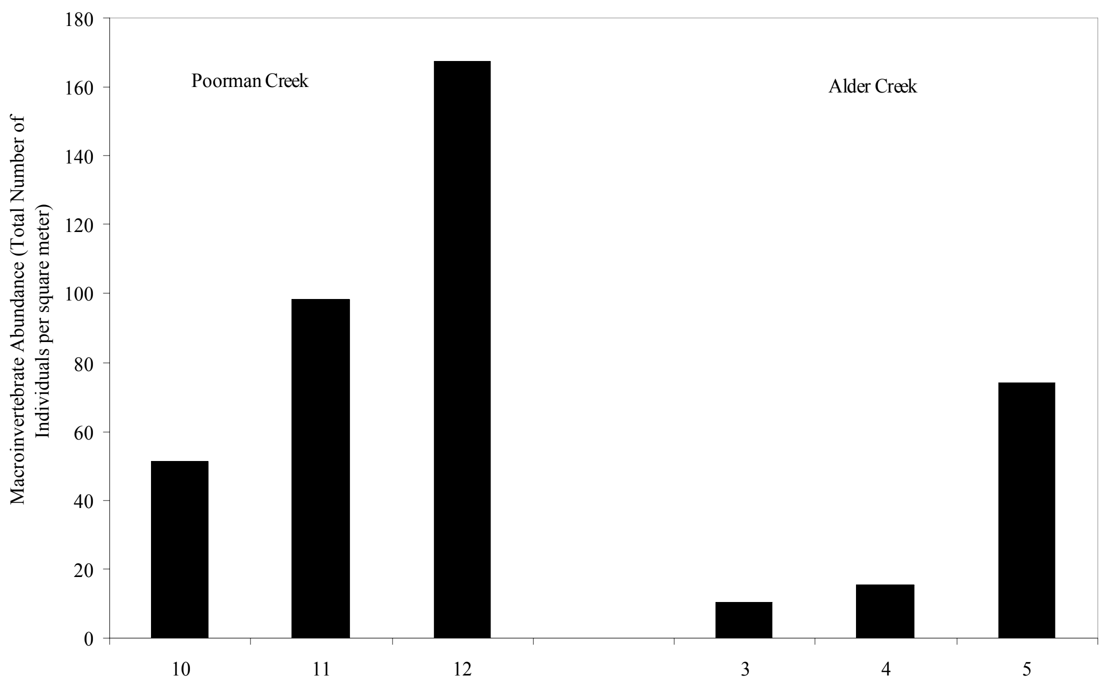

Figure 21. Total Abundance of benthic macroinvertebrates in relation to stream location for the reference stream (Poorman Creek) and the test stream (Alder Creek).

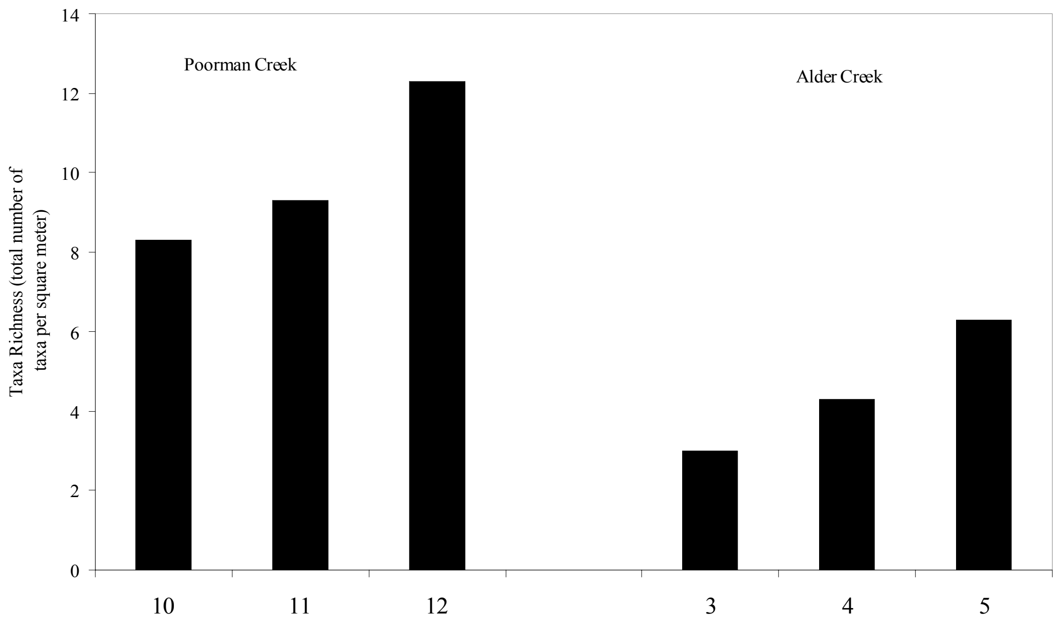

Figure 22. Taxa richness (number of taxa identified per Surber sample) in relation to stream location for the reference stream (Poorman Creek) and the test stream (Alder Creek).

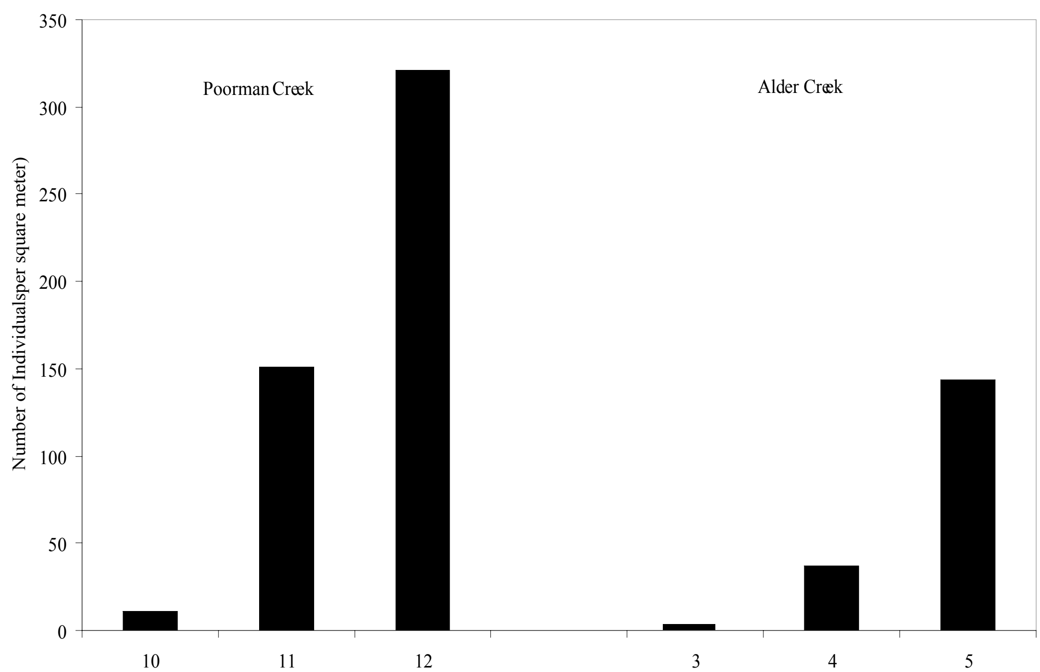

Figure 23. Incidence of Baetis sp (Fam. Ephemeroptera, Mayflies) in relation to stream location for the reference stream (Poorman Creek) and the test stream (Alder Creek).

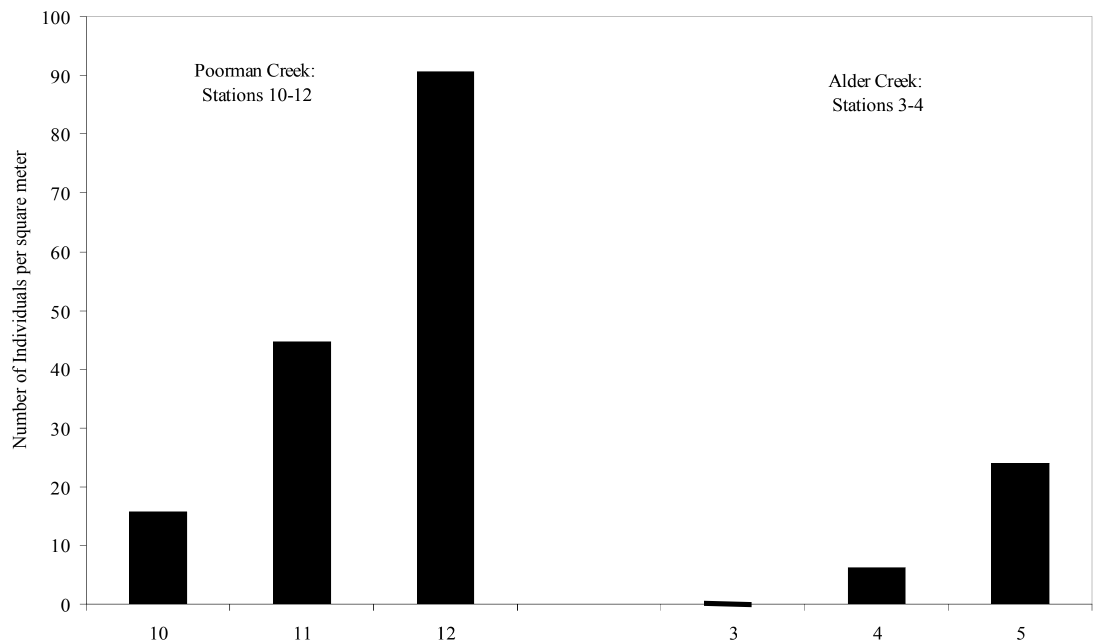

Figure 24. Incidence of Ephemeroptera in relation to stream location for the reference stream (Poorman Creek) and the test stream (Alder Creek).

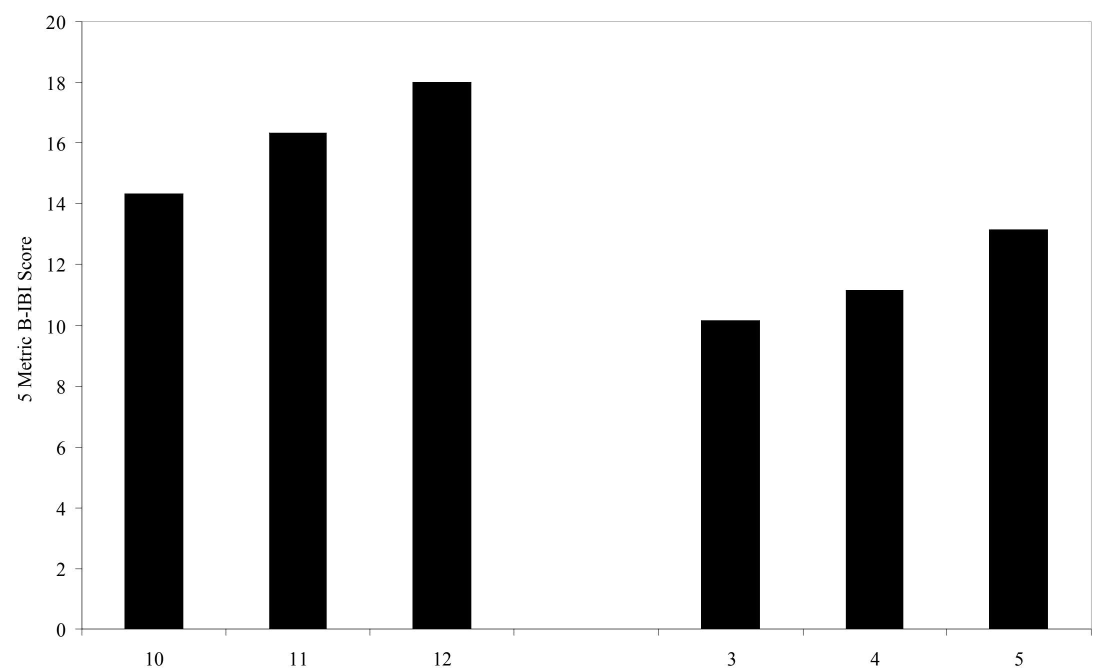

Figure 25. Five-metric B-IBI score in relation to stream location for the reference stream (Poorman Creek) and the test stream (Alder Creek)

CONCLUSIONS

Alder Creek and Poorman Creek are similar based on physicochemical parameters such as dissolved oxygen, pH, temperature, and alkalinity. Current velocity, streamflow, substrate size, and vegetation were also comparable.

Heavy metal-laden water from two portals of abandoned mine tunnels, one acid and one alkaline, most likely have separate hydrologic sources or originate from separate mineral deposits. The dominance of Zn and Cd in the mine drainage is consistent with the geological maps prepared by Barksdale (1975) that indicate that the ore deposits contain the sulfide minerals sphalerite and chalcopyrite in addition to pyrite.

Over 90% of the more than 11,000 kg of metals discharged annually from the mine tunnels are retained by the forest soils between the mine and creek making soil the principal reservoir for the deposition of elements delivered to the environment. The annual mass loading at the Alder Creek site nearest the mill outfall, estimated to be over 800 kg of metals annually, appears to be present almost entirely as biologically available solutes.

Stream water metal concentrations relative to Washington state water quality criteria indicate that Zn, Cu, Cr, Se, and Cd are present at levels that pose a risk of causing environmental problems. The relative order of Zn and Cd mobility appears to be consistent with the order of their concentration in the stream water (i.e., is Se-10 km > Zn-1 km > Cd-0.5 km > Cu-0 km). Selenium, however, appears to be the most mobile, impacts the largest area, and poses the most significant threat to juvenile salmonids in the pools at the confluence of Alder Creek and the Methow River.

The concentration of Zn and Cd in sediments, and their distribution downstream is consistent with that in the stream water. While there are no sediment criteria for Se, its presence at levels approximately 2 times the level of sediments in Poorman Creek combined with the possibility that it could be a source of the element to be released back into the water column and its known its toxicity to young-of-the-year trout, make this element a potentially hazardous pollutant.

Deficiencies in the benthic fauna community structure in Alder Creek relative to Poorman Creek and the elevated concentrations of Cd, Cu, Se and Zn in the stream waters and sediments indicate that these metals might exercise the greatest influence on Ephemeropterans. Simulidae, which increased in the presence of heavy metals, appears to be a metal-tolerant opportunist that dominated the benthic community in Alder Creek. *Zapada, Malenka,* Limnochaidae, and *Gammarus* were also encountered at greater densities in Alder Creek than in Poorman Creek. *Baetis,* due to its ubiquitous distribution and its sensitivity to metals that is reflected in the negative correlation of abundance with metal concentrations makes it an ideal candidate for study as an indicator taxon.

The benthic community structure was meaningfully different at the 5% level of significance. The 5-metric index of biotic integrity, which combines taxa richness, the EPT index, and taxa dominance demonstrated that the contamination of Alder Creek with effluent from the Alder Mine has had a measurable impact on the aquatic biota of Alder Creek. Using the principles of epidemiology, a strong relationship has been established between the discharge of metal-laden mine waste from the abandoned Alder Mine, elevated levels of Cd, Cu, Se and Zn in Alder Creek, and the effects on the aquatic fauna of Alder Creek. The extent of the problem, reaching the confluence of Alder Creek and the Methow River indicates that there exists a significant hazard to the environment.

LITERATURE CITED

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APPENDIX A

Physicochemical Data

Date	Site	Current Speed (m/sec)	Flow (cms)	Flow (cfs)
5/2/98	9	0.99	0.06	2.04
5/2/98	1	1.28	0.09	3.16
5/2/98	2	1.04	0.12	4.27
5/2/98	3	1.12	0.17	6.11
5/2/98	4	0.98	0.09	3.01
5/2/98	5	1.51	0.20	7.20
5/2/98	6	0.80	0.26	9.20

Date	Site	Current Speed (m/sec)	Flow (cms)	Flow (cfs)
6/18/98	10	0.17	0.01	0.36
6/18/98	11	0.55	0.07	2.36
6/18/98	12	0.81	0.71	25.05
6/18/98	9	0.56	0.02	0.87
6/18/98	1	0.27	0.00	0.15
6/18/98	2	0.42	0.03	1.23
6/18/98	3	0.28	0.04	1.24
6/18/98	4	0.98	0.09	3.01
6/18/98	5	0.46	0.07	2.43
6/18/98	6	1.00	0.23	8.15

Date	Site	Current Speed (m/sec)	Flow (cms)	Flow (cfs)
7/8/98	3	0.49	0.04	1.39
7/15/98	3	0.39	0.02	0.77
7/22/98	3	0.35	0.02	0.62
7/30/98	3	0.29	0.01	0.52
8/6/98	3	0.16	0.01	0.22
8/11/98	3	0.14	0.00	0.15
8/19/98	3	0.14	0.01	0.18
8/28/98	3	0.14	0.01	0.18

Date	Site	Current Speed (m/sec)	Flow (cms)	Flow (cfs)
9/2/98	10	0.13	0.00	0.12
9/2/98	11	0.26	0.04	1.50
9/2/98	12	0.31	0.05	1.67
9/2/98	9	0.09	0.00	0.05
9/2/98	1	0.09	0.00	0.02
9/2/98	2	0.12	0.00	0.08
9/2/98	3	0.15	0.00	0.16
9/2/98	4	0.13	0.01	0.19
9/2/98	5	0.31	0.01	0.37
9/2/98	6	0.65	0.08	2.66

APPENDIX B

Chemical Data

High-Flow Metal Concentration (Filtered: µg/ml). For description of sample stations see site map Figure 2. TR = Trace, ND = Not Detectable.

Site	As	criteria	Cd	criteria	Cr	criteria	Cu	criteria	Ni	criteria
10	0	360	0	10	48	16	0	37	0	3015
10	0	360	0	10	49	16	0	37	0	2998
10	0	360	9	10	55	16	0	37	0	3003
11	0	360	9	10	56	16	0	37	0	2985
11	0	360	9	10	51	16	0	37	0	2966
11	0	360	0	10	51	16	0	36	0	2941
12	0	360	0	10	55	16	0	38	0	3023
12	0	360	0	10	50	16	0	37	0	2970
12	0	360	0	10	50	16	0	37	0	2947
9	0	360	0	10	51	16	0	37	0	2996
9	15	360	0	10	45	16	0	36	0	2932
9	0	360	0	9	42	16	0	36	0	2904
1	0	360	0	17	64	16	0	58	0	4441
1	0	360	0	17	65	16	0	58	0	4444
1	0	360	0	17	63	16	0	57	0	4425
2	0	360	0	14	51	16	0	49	0	3826
2	0	360	0	13	54	16	0	48	0	3789
2	0	360	0	15	65	16	0	52	0	4030
3	0	360	111	16	75	16	132	55	0	4257
3	0	360	111	15	78	16	128	54	0	4200
3	0	360	104	15	77	16	127	54	0	4178
4	0	360	30	14	66	16	0	51	0	3990
4	0	360	9	14	45	16	0	51	0	3975
4	0	360	9	14	46	16	0	51	0	3953
5	0	360	9	15	64	16	0	53	0	4100
5	0	360	9	15	61	16	0	52	0	4028
5	0	360	9	14	61	16	0	51	0	4001
6	0	360	9	14	74	16	0	51	0	3960
6	0	360	9	14	73	16	0	50	0	3929
6	0	360	0	15	59	16	0	52	0	4070
13	0	360	4514	67	169	16	22851	184	98	12602
13	0	360	4500	65	176	16	21563	180	90	12320
13	0	360	4764	68	183	16	21954	186	101	12730
16	0	360	169	19	72	16	895	65	0	4974
16	0	360	178	20	82	16	867	66	0	5041
16	0	360	191	20	100	16	810	67	0	5053

High-Flow Metal Concentration (Filtered: µg/ml). For description of sample stations see site map Figure 2. TR = Trace, ND = Not Detectable.

Site	Pb	criteria	Se	criteria	Zn	criteria	Ca	Mg	Fe	S
10	0	189	0	20	0	234	84	12	10	14633
10	0	187	30	20	0	232	84	12	10	14683
10	0	187	30	20	0	233	85	11	10	14799
11	0	186	30	20	0	231	86	10	10	16676
11	0	184	30	20	0	230	85	10	10	16677
11	0	182	30	20	0	228	84	10	10	16282
12	0	189	0	20	0	234	85	12	10	17281
12	0	184	30	20	0	230	83	11	10	16929
12	0	182	30	20	0	228	82	11	10	17014
9	30	187	30	20	0	232	84	12	10	23732
9	30	181	30	20	0	227	81	12	10	23106
9	0	178	30	20	0	225	80	11	10	23004
1	30	338	30	20	0	344	99	40	30	20650
1	30	338	30	20	0	345	99	39	31	20818
1	30	336	30	20	0	343	98	40	10	20713
2	0	270	30	20	0	297	101	22	10	33926
2	0	266	30	20	0	294	100	22	10	33596
2	0	292	30	20	0	312	109	23	34	35225
3	30	317	30	20	6430	330	113	26	39	51738
3	30	310	30	20	6435	326	112	25	40	51118
3	0	308	30	20	6096	324	111	25	38	49955
4	30	287	30	20	1050	309	106	24	10	30295
4	0	286	30	20	1008	308	102	25	10	30165
4	30	283	30	20	1000	306	101	25	10	30298
5	0	299	30	20	710	318	106	26	31	30497
5	0	291	30	20	702	312	104	26	10	29864
5	0	288	30	20	689	310	103	25	10	29542
6	0	284	30	20	0	307	101	25	45	31719
6	0	281	30	20	0	305	100	25	37	31477
6	0	296	30	20	0	315	102	28	10	32800
13	517	1621	1182	20	315033	979	223	206	25207	705965
13	534	1567	1273	20	314542	957	221	198	24574	692781
13	558	1646	1298	20	329590	989	235	203	25641	724074
16	0	400	30	20	12144	386	117	43	34	76130
16	0	409	30	20	12480	391	121	42	41	77721
16	30	410	288	20	12783	392	125	40	50	77705

High-Flow Metal Concentration (Uniltered: µg/ml). For description of sample stations see site map Figure 2. TR = Trace, ND = Not Detectable.

Station	As ug/kg	criteria	Cd	criteria	Cr	criteria	Cu	criteria	Ni	criteria
10	0	360	0	10	44	16	0	37	0	2963
10	0	360	0	9	42	16	0	36	0	2906
10	0	360	0	10	45	16	19	36	85	2921
11	0	360	9	10	53	16	0	37	0	2963
11	0	360	0	10	48	16	0	37	0	2949
11	0	360	0	10	56	16	0	37	0	2999
12	0	360	0	10	54	16	0	38	0	3020
12	15	360	0	10	52	16	0	37	0	2991
12	0	360	0	10	53	16	0	37	0	2984
9	0	360	0	10	49	16	0	36	0	2940
9	0	360	0	10	50	16	0	37	0	2946
9	0	360	0	10	38	16	0	36	0	2924
1	0	360	0	17	65	16	0	59	0	4503
1	0	360	9	17	67	16	0	58	0	4475
1	0	360	0	17	69	16	0	58	0	4450
2	0	360	0	14	54	16	0	50	0	3877
2	0	360	0	14	53	16	0	49	0	3870
2	0	360	0	14	52	16	0	49	0	3831
3	0	360	105	16	67	16	148	55	0	4284
3	0	360	110	16	72	16	143	55	0	4253
3	0	360	107	16	76	16	153	54	0	4211
4	0	360	9	15	51	16	16	52	0	4012
4	0	360	36	14	68	16	0	51	0	3997
4	0	360	9	14	38	16	0	51	0	3957
5	0	360	9	14	41	16	0	51	0	3988
5	0	360	9	15	65	16	0	52	0	4071
5	0	360	9	15	62	16	0	52	0	4080
6	0	360	9	14	77	16	0	51	0	4003
6	0	360	9	15	73	16	0	52	0	4024
6	0	360	0	15	50	16	0	51	0	4011
13	0	360	4781	66	195	16	21123	183	97	12514
13	0	360	4947	66	209	16	20293	183	106	12547
13	0	360	5071	71	198	16	22326	193	101	13161
16	0	360	170	19	78	16	1052	66	0	4980
16	0	360	176	20	78	16	1079	67	0	5093
16	0	360	186	20	92	16	974	66	3	5018

High-Flow Metal Concentration (Uniltered: µg/ml). For description of sample stations see site map Figure 2. TR = Trace, ND = Not Detectable.

Station	Pb	criteria	Se	criteria	Zn	criteria	Ca	Mg	Fe	S
10	0	184	0	20	0	230	82	12	38	14432
10	0	178	30	20	0	225	80	11	31	14091
10	0	180	0	20	0	226	81	11	38	14257
11	0	184	30	20	0	230	85	10	44	16435
11	0	182	30	20	0	228	84	10	46	16578
11	0	187	30	20	0	232	86	11	57	16565
12	0	189	30	20	0	234	85	11	83	17206
12	0	186	30	20	0	232	84	11	66	17164
12	0	186	30	20	0	231	84	11	70	17166
9	30	181	30	20	0	228	82	11	41	23255
9	0	182	30	20	0	228	82	11	59	23396
9	0	180	30	20	0	227	81	12	35	23132
1	30	345	30	20	0	349	101	40	126	20949
1	30	341	30	20	0	347	100	39	144	20754
1	30	339	30	20	0	345	100	39	142	20650
2	0	275	30	20	0	301	103	22	35	34561
2	0	274	30	20	0	300	103	22	35	34449
2	0	270	30	20	0	297	101	22	34	34247
3	30	320	30	20	6463	332	112	27	46	52280
3	0	316	30	20	6512	330	112	26	43	51885
3	30	312	30	20	6224	326	112	26	72	50319
4	0	290	30	20	1099	311	104	25	32	30594
4	0	288	30	20	1080	310	106	23	43	30387
4	30	284	0	20	1013	307	100	26	10	30163
5	0	287	30	20	706	309	101	26	34	29690
5	0	296	30	20	740	316	106	25	43	30174
5	30	297	30	20	739	316	106	26	42	30227
6	30	289	30	20	0	310	103	26	96	32075
6	0	291	30	20	0	312	103	26	61	32179
6	0	290	30	20	0	311	100	28	41	32000
13	580	1604	1295	20	333965	972	235	196	26929	716660
13	581	1611	1432	20	343906	974	243	192	26380	723964
13	603	1731	1383	20	349326	1022	251	207	28131	759566
16	0	401	30	20	12401	386	118	42	78	76262
16	0	415	30	20	12661	395	121	44	78	78831
16	30	406	251	20	12747	389	123	41	86	77230

Low-Flow Metal Concentration (Filtered: µg/ml). For description of sample stations see site map Figure 2. TR = Trace, ND = Not Detectable.

Station	As	Criteria	Cd	Criteria	Cr	Criteria	Cu	Criteria	Ni	Criteria
10	0	360	9	11	86	16	0	41	0	3259
10	0	360	9	11	82	16	0	40	0	3177
10	0	360	9	11	84	16	0	40	0	3177
11	0	360	9	10	80	16	0	38	0	3077
11	0	360	9	10	79	16	0	38	0	3067
11	0	360	9	10	84	16	0	39	0	3125
12	0	360	9	11	83	16	0	40	0	3179
12	0	360	9	9	59	16	0	35	0	2821
12	0	360	9	9	55	16	0	34	0	2741
9	0	360	9	11	88	16	0	40	0	3199
9	0	360	9	11	91	16	0	40	0	3230
9	0	360	9	11	87	16	0	40	0	3173
1	0	360	9	16	98	16	0	56	0	4342
1	0	360	9	16	95	16	0	57	0	4402
1	0	360	9	16	94	16	0	56	0	4310
2	0	360	9	17	103	16	0	59	0	4558
2	0	360	9	17	99	16	0	59	0	4507
2	0	360	9	17	101	16	0	59	0	4548
3	0	360	120	18	107	16	4	62	0	4764
3	0	360	118	18	105	16	0	62	0	4740
3	0	360	120	18	105	16	0	63	0	4789
4	0	360	9	14	86	16	0	51	0	4002
4	0	360	9	14	84	16	0	51	0	3994
4	0	360	35	16	102	16	0	56	0	4336
5	0	360	9	15	91	16	0	53	0	4117
5	0	360	9	15	88	16	0	53	0	4097
5	0	360	9	15	86	16	0	52	0	4043
6	0	360	9	14	86	16	0	51	0	3966
6	0	360	9	14	84	16	0	51	0	3960
6	0	360	9	14	85	16	0	51	0	3958

Low-Flow Metal Concentration (Filtered: µg/ml). For description of sample stations see site map Figure 2. TR = Trace, ND = Not Detectable.

Station	Pb	Criteria	Se	Criteria	Zn	Criteria	Ca	Mg	Fe	S
10	0	212	30	20	0	253	94	12	45	17833
10	0	204	30	20	0	246	91	12	43	17226
10	0	204	30	20	0	246	91	12	40	17318
11	0	194	30	20	0	238	87	11	48	17952
11	0	193	30	20	0	238	87	12	52	17974
11	0	199	30	20	0	242	89	12	62	18293
12	0	204	30	20	0	246	89	13	70	19645
12	0	170	30	20	0	219	76	12	52	16697
12	0	163	30	20	0	212	73	12	52	16171
9	0	206	225	20	2	248	89	14	158	26993
9	0	209	236	20	2	250	90	14	538	27007
9	0	204	30	20	0	246	88	14	187	26736
1	0	326	228	20	0	337	123	22	50	36550
1	0	333	238	20	0	341	124	23	46	37297
1	0	323	30	20	0	334	121	22	45	36201
2	0	351	260	20	0	353	130	24	85	40179
2	0	345	265	20	0	349	128	24	77	39725
2	0	350	243	20	0	353	129	24	78	40171
3	0	375	285	20	4385	369	124	33	61	75949
3	0	372	258	20	4341	368	123	33	54	75776
3	0	378	260	20	4380	371	124	33	54	76326
4	0	289	251	20	401	310	100	27	42	30315
4	0	288	30	20	399	310	100	27	41	30200
4	0	326	266	20	447	336	112	29	52	34226
5	0	301	236	20	218	319	104	28	45	29836
5	0	299	232	20	218	318	103	28	45	29767
5	0	293	253	20	213	313	101	28	44	29286
6	0	285	30	20	0	307	97	28	69	31426
6	0	284	30	20	0	307	97	28	66	31372
6	0	284	233	20	0	307	97	28	72	31402

Low-Flow Metal Concentration (Uniltered: µg/ml). For description of sample stations see site map Figure 2. TR = Trace, ND = Not Detectable.

Station	As	Criteria	Cd	Criteria	Cr	Criteria	Cu	Criteria	Ni	Criteria
10	0	360	9	11	84	16	0	40	0	3170
10	0	360	9	11	82	16	0	39	0	3149
10	0	360	9	10	81	16	0	39	0	3141
11	0	360	9	10	80	16	0	38	0	3057
11	0	360	9	10	79	16	0	38	0	3055
11	0	360	9	10	80	16	0	38	0	3057
12	0	360	9	11	80	16	0	39	0	3144
12	0	360	9	9	54	16	0	34	0	2732
12	0	360	0	9	55	16	0	33	0	2725
9	0	360	9	11	88	16	0	40	0	3166
9	0	360	9	10	87	16	0	39	0	3105
9	15	360	9	10	88	16	0	39	0	3137
1	0	360	9	16	91	16	0	55	0	4278
1	0	360	9	16	95	16	0	57	0	4362
1	0	360	9	16	108	16	0	57	0	4387
2	0	360	9	17	102	16	0	59	0	4535
2	0	360	9	17	99	16	0	59	0	4508
2	0	360	9	17	99	16	0	59	0	4499
3	0	360	117	18	104	16	0	62	0	4727
3	0	360	119	18	104	16	0	63	0	4796
3	0	360	116	18	103	16	0	62	0	4738
4	0	360	9	14	85	16	0	51	0	3960
4	0	360	35	16	99	16	0	56	0	4330
4	0	360	35	16	98	16	0	55	0	4237
5	0	360	9	15	90	16	0	53	0	4088
5	0	360	9	15	88	16	0	52	0	4043
5	0	360	9	14	86	16	0	51	0	3979
6	0	360	9	14	84	16	0	50	0	3911
6	0	360	9	14	84	16	0	50	0	3912
6	0	360	9	15	92	16	0	53	0	4103

Low-Flow Metal Concentration (Uniltered: µg/ml). For description of sample stations see site map Figure 2. TR = Trace, ND = Not Detectable.

Station	Pb	Criteria	Se	Criteria	Zn	Criteria	Ca	Mg	Fe	S
10	0	203	30	20	0	246	91	12	39	17287
10	0	201	30	20	0	244	90	12	35	17051
10	0	200	30	20	0	243	90	12	35	16978
11	0	192	30	20	0	237	87	11	37	17729
11	0	192	30	20	0	237	87	11	35	17861
11	0	192	30	20	0	237	87	11	36	17850
12	0	201	30	20	0	244	87	13	37	19470
12	0	163	30	20	0	212	73	12	9	16144
12	0	162	30	20	0	211	72	12	9	16068
9	0	203	30	20	0	245	87	14	53	26672
9	0	197	30	20	0	241	86	13	49	25948
9	0	200	30	20	0	243	86	14	45	26488
1	0	319	232	20	0	332	120	22	43	35870
1	0	329	249	20	0	338	123	23	44	36854
1	0	331	268	20	0	340	125	22	57	36900
2	0	348	263	20	0	352	129	24	52	39745
2	0	345	259	20	0	350	128	24	48	39423
2	0	344	265	20	0	349	127	24	49	39651
3	0	371	271	20	4291	366	122	33	50	75229
3	0	379	271	20	4376	372	124	34	50	76750
3	0	372	297	20	4297	367	123	33	50	75511
4	0	284	243	20	389	307	99	27	39	29878
4	0	325	253	20	439	336	112	29	51	34041
4	0	314	259	20	432	328	109	28	47	33303
5	0	298	251	20	211	317	103	28	42	29599
5	0	293	227	20	209	313	101	28	41	29255
5	0	286	231	20	205	308	99	27	40	28705
6	0	279	30	20	0	303	95	28	49	30784
6	0	279	238	20	0	303	95	28	50	30880
6	0	300	263	20	0	318	102	29	55	31674

High-Flow Sediment Metal Concentration (μg/g). For description of sample stations see site map Figure 2. TR = Trace, ND = Not Detectable.

Station	Cd	Cr	Cu	Fe	Ni	Pb	Se	Zn
10	8	15	22	29224	8	11	148	90
10	9	16	25	33186	10	TR	212	101
10	10	17	27	36250	10	12	223	109
11	9	15	18	29872	8	12	195	77
11	9	18	19	32326	9	10	197	87
11	8	17	21	29117	9	10	159	85
12	9	20	18	30469	9	9	227	86
12	8	18	18	29186	8	TR	183	85
12	9	19	18	30803	10	12	205	93
9	7	19	34	24611	10	10	120	164
9	7	19	31	25249	11	10	119	167
9	7	20	33	25258	9	TR	124	166
1	TR	22	43	11034	TR	TR	ND	71
1	TR	23	49	10221	TR	TR	ND	71
1	TR	21	40	10020	TR	TR	ND	66
2	6	16	49	19930	9	10	79	300
2	10	20	62	25996	9	11	151	418
2	8	20	56	24107	10	9	136	362
3	59	14	207	21228	11	11	102	5872
3	194	14	540	18186	15	TR	43	###
3	32	14	104	23207	9	TR	138	2895
4	69	20	67	18944	9	ND	66	5118
4	85	19	59	15700	9	TR	ND	5749
4	78	21	70	19969	9	TR	47	5425
5	95	21	95	12406	7	TR	ND	3900
5	40	22	37	17452	9	TR	TR	2763
5	54	21	41	15318	8	TR	TR	2871
6	10	25	34	30746	10	TR	270	106
6	10	30	40	34505	13	TR	328	105
6	11	31	43	35831	13	ND	341	102

Low-Flow Sediment Metal Concentration (μg/g). For description of sample stations see site map Figure 2.

Station	Cd	Cr	Cu	Fe	Ni	Pb	Se	Zn
10	10	22	22	30909	9	TR	339	119
10	9	24	31	29932	9	TR	319	101
10	12	27	29	35857	11	10	394	109
11	11	23	19	31096	8	TR	341	83
11	10	23	19	28912	7	8	327	79
11	10	23	21	29379	9	9	337	85
12	11	25	20	29913	9	TR	353	93
12	11	24	19	30765	8	TR	348	87
12	10	24	22	27636	8	TR	324	83
9	10	27	32	28109	11	TR	311	175
9	9	25	76	25413	8	TR	289	169
9	9	25	34	24941	11	TR	279	149
1	10	31	31	28623	12	TR	317	155
1	8	23	36	23394	9	TR	263	152
1	8	22	28	22156	8	TR	246	146
2	13	28	60	25125	10	TR	270	638
2	11	25	44	24487	9	10	263	428
2	10	22	43	22016	7	20	243	384
3	36	21	106	25428	11	ND	285	6948
3	52	21	92	24519	11	TR	281	7571
3	50	20	112	26093	10	TR	295	7351
4	43	23	44	19490	9	TR	225	4836
4	44	23	44	20509	9	ND	235	5118
4	47	26	49	21465	10	TR	242	4918
5	68	27	36	14319	7	ND	179	2685
5	66	26	31	13643	8	ND	168	2259
5	45	28	34	18805	8	TR	226	2976
6	14	41	38	37664	14	TR	531	93
6	13	38	39	36692	14	TR	505	93
6	13	39	48	37340	13	ND	522	112

APPENDIX C

Biological Data

Benthic Macroinvertebrate Surber Data (Poorman Creek and Alder Creek) June 1998 through September 1998.

Station Number:	9			9			10			10			11		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
F. Ceratopognidae	1	1	1		9	1	1			1	1			4	1
F. Chironomidae			2	15	15	19	6			5	3	4	1		
F. Dixidae				3	20	5						10			
F. Pelecorhynchidae		2			1					3				1	
F. Psychodidae					1	3				6	5	3			
F. Simulidae	3		6	5				1							
F. Tipulidae				2							2	1		1	
F. Tabanidae															
Baetis	2	3	15	5	21	25				9	2		23	10	4
Drunella									1						
Ephemerella							4		3	2	2		5	2	7
Seratella								1							
Cinygmula	7	8	15	1	11	4	32		12	8	12	4	23		14

Station Number:	11			12			12			3			3		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
F. Ceratopognidae	1		2		2			3	3	1					
F. Chironomidae	4	3	6	2	1		2	13	7			1	3	2	1
F. Dixidae									1						
F. Pelecorhynchidae	3		1					2	3						
F. Psychodidae	7		4					1	2						
F. Simulidae							1	1		2		5			
F. Tipulidae					1			3	1						
F. Tabanidae				1		15									
Baetis	12	47	59	91	57	48	29	67	86						
Drunella															
Ephemerella		4		14	10	4	1	3	2						
Seratella							1								
Cinygmula	8	24	23	15	37	17	13	19	25						

Benthic Macroinvertebrate Surber Data (Poorman Creek and Alder Creek) June 1998 through September 1998.

Station Number:	4			4			5			5			6			6		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
F. Ceratopognidae					1													
F. Chironomidae				3	1	1	1			3	2	2	1	5	3		1	4
F. Dixidae																		
F. Pelecorhynchidae																		
F. Psychodidae																		
F. Simulidae	1							3	4				13			1	4	6
F. Tipulidae										1	2				2	1		
F. Tabanidae																		
Baetis	20		8	5	1	3		16	19	36	40	33		3	8	11	38	28
Drunella																		
Ephemerella																3		
Seratella																		
Cinygmula							1											

Station Number:	9			9			10			10			11		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Ironodes								2					2		
Epeorus															
Paraleptophlebia															
Chloroperlidae	1	5	2	15	27	13	11	8	1	16	11	1	12	6	5
Luctridae	3														
Capniidae															
Malenka			1	2						8	2		1		
Zapada		6		4		4			1						
Yoraperla													4		4
Doroneuria															
Isoperla						5									
Megarcys	2										1				
Pteronarcys										2					

Benthic Macroinvertebrate Surber Data (Poorman Creek and Alder Creek) June 1998 through September 1998.

Station Number:	11			12			12			3			3		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Ironodes				1											
Epeorus				2	1										
Paraleptophlebia			1						1						
Chloroperlidae	24	16	17	9	6	4		29	27	1		1	5	8	2
Luctridae															
Capniidae													5	5	
Malenka	4	3	3		1	1	2								
Zapada	1						1	9	9				3		
Yoraperla	1	5	10	3		2	13	2	3						
Doroneuria	2		14	2	1		2	4							
Isoperla									2						
Megarcys									3						
Pteronarcys	4		4				7	1	2						

Station Number:	4			4			5			5			6			6		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Ironodes																		
Epeorus																		
Paraleptophlebia																		
Chloroperlidae					4	1	2		8	5	10	3	10					
Luctridae																		
Capniidae																		
Malenka		1					3		1	5				22	21	13	4	10
Zapada			1	7	3	1	1			94	31	25					1	17
Yoraperla																		
Doroneuria	2		1					1										
Isoperla											1	3						1
Megarcys				2						4								
Pteronarcys										2								

Benthic Macroinvertebrate Surber Data (Poorman Creek and Alder Creek) June 1998 through September 1998.

Station Number:		9			9			10			10			11	
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Brachycentrus															
Anagapetus	1	1	2	5	6	5	2	1	14					1	
Glossoma									2						
Parapsyche	2			2	1					2	3	2			
Leuchotrichia									1						
Lepidostoma															
Allomyia															
Chyranda									1						
Clostoeca					2										
Cryptochia	1				1										
Cyrnellus															
Nyctiophylax															
Rhyacophila	2			2	2	5				4	1	1		1	1

Station Number:		11			12			12			3			3	
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Brachycentrus															
Anagapetus		1			1	1	8	7	2		1	3		2	1
Glossoma		1													
Parapsyche	1	3	8		1		3	8							
Leuchotrichia								1							
Lepidostoma						1									
Allomyia		1													
Chyranda															
Clostoeca															
Cryptochia															
Cyrnellus															
Nyctiophylax															
Rhyacophila	1	4	11	3			5	7	8			3			

Benthic Macroinvertebrate Surber Data (Poorman Creek and Alder Creek) June 1998 through September 1998.

Station Number:	4			4			5			5			6			6		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Brachycentrus														2				
Anagapetus	3	3	3					4	2	1	1	2						
Glossoma																		
Parapsyche										2				1	6	1	1	3
Leuchotrichia																		
Lepidostoma	2												1					1
Allomyia											1			1				
Chyranda																		
Clostoeca																		
Cryptochia																		
Cyrnellus																		
Nyctiophylax																		
Rhyacophila				2	1					5	2	2				3		

Station Number:	9			9			10			10			11		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Himalopshche									1						1
Heterlimnius							1	1	4	13	7	8	1		4
Optioservus			1												
Argia															
F. Limnocharidae															
Gammarus															
F. Formicidae															
O. Nematomorpha															
O. Entognatha															
F. Lumbricidae															
F. Naididae															
P. Nemertina				8	38	8									

Benthic Macroinvertebrate Surber Data (Poorman Creek and Alder Creek) June 1998 through September 1998.

Station Number:	11			12			12			3			3		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Himalopshche															
Heterlimnius	5	11	22	15	21	4	20	14	18						
Optioservus															
Argia															
F. Limnocharidae															
Gammarus															
F. Formicidae															
O. Nematomorpha			1												
O. Entognatha			1												
F. Lumbricidae			1												
F. Naididae								1							
P. Nemertina			2				1								

Station Number:	4			4			5			5			6			6		
Replication Number :	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Himalopshche																		
Heterlimnius						3	1		1	3		3	2	22	12	14	15	12
Optioservus																		9
Argia												1	1	1				
F. Limnocharidae										2		2	1	8	9		5	28
Gammarus												1			2	3	17	2
F. Formicidae																		
O. Nematomorpha																		
O. Entognatha																		
F. Lumbricidae									1									
F. Naididae																		
P. Nemertina										1							2	

APPENDIX D

Budget Summary

UW Budget Name: Alder Creek
UW Budget Number: 62-0769
Budget Period: 06/01/98 through 11/30/98

Budget Category	Budget Amount	Actual	Budget Balance
01	13308.00	12751.00	557.00
03	3315.00	5038.00	(1723.60)
04	1000.00	791.60	208.40
05	1500.00	283.46	1216.54
07	1231.00	1078.13	152.87
08	4896.00	4895.00	1.00
Direct Costs	25250.00	24837.79	412.21
25	5292.00	5292.00	
Total	30542.00	30129.79	412.21

Capital Equipment and Laboratory Items Greater than $100.00 per Unit

1. Piccolo hand held pH meter 182.00
2. Drift Net 199.00

Key to Budget Categories

O1 Salaries and Wages
03 Other Contractual Services (Chemical Analyses)
04 Travel (Mileage to Sample Sites)
05 Supplies and Materials (Chemicals and Laboratory Supplies)
07 Benefits
08 Graduate Operating Fees